Commissioning of the ATLAS Experiment

Jürgen Thomas
(University of Birmingham, UK)
for the ATLAS Collaboration

HCP2008: 19th Hadron Collider Physics Symposium 2008
Galena, IL, USA

Outline:

- Introduction
- Calorimetry
- Muon Detectors
- Inner Tracking Detectors
- Trigger/DAQ
- Looking ahead

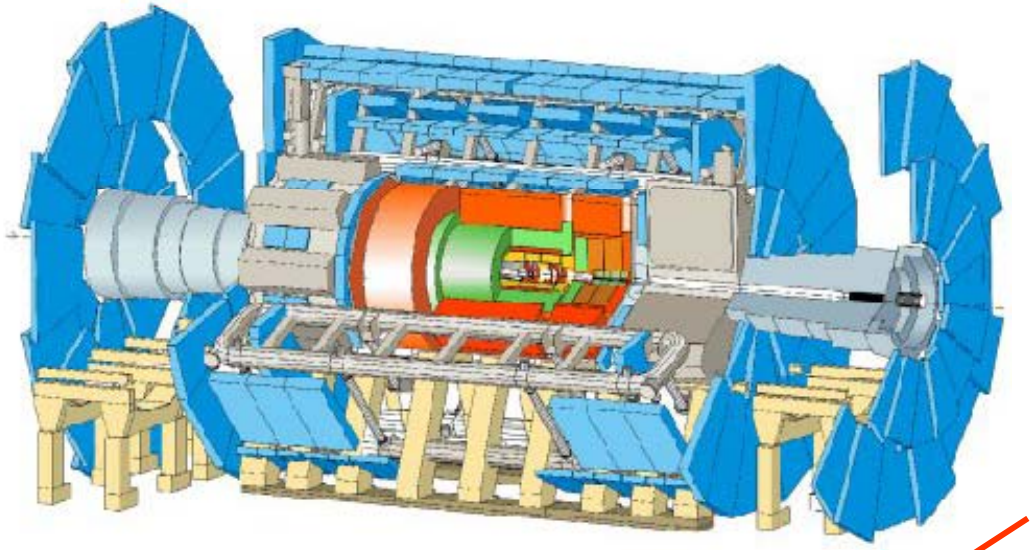
Introduction

The ATLAS Collaboration

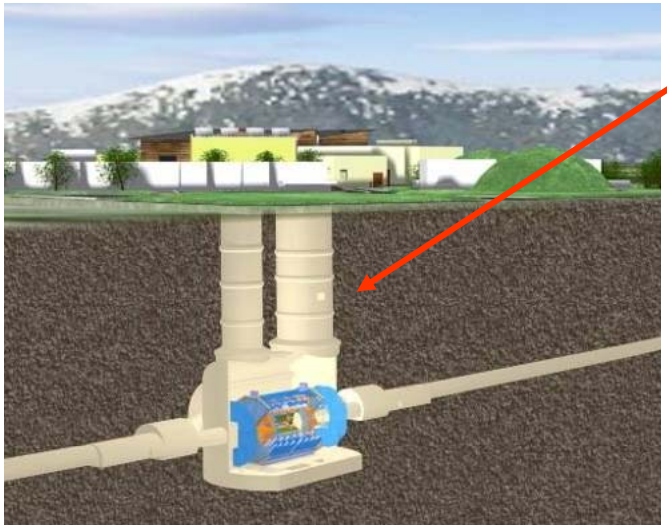
- 1 Experiment
- 35 Countries (with collaborating institutes, many more countries of origin)
- 165 Institutes (as of July 2007)
- 1900 scientific authors

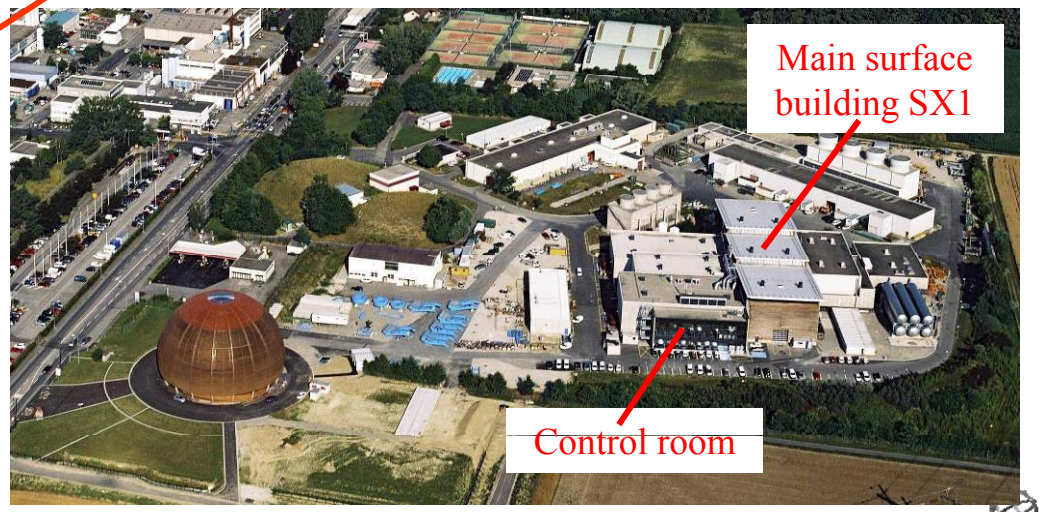
Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Goettingen, LPSC Grenoble, Technion Haifa, Hamburg, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QM London, RH London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

The ATLAS Detector



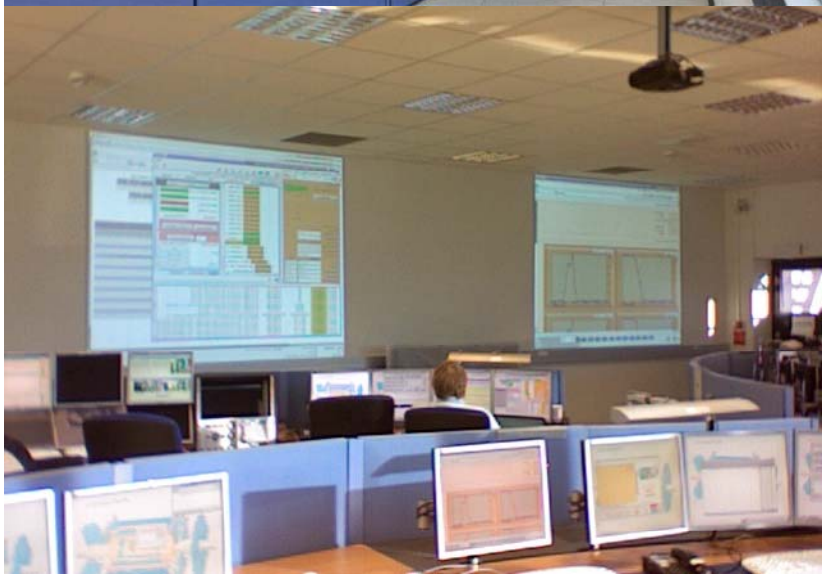
- 25m diameter
- 46m total length
- 7000t weight
- installed just across the CERN main site, 92 meters below ground
- ATLAS cavern: 55m long, 32m wide, 35m high: just large enough for the detector – 'ship in a bottle', assembled in situ





The Schedule: Working towards Data-Taking

- **Milestone weeks (Mx)**: Dedicated effort bringing all experts together with defined targets:
  - Preparation days
  - Combined runs on weekends runs in different configurations with much of the detector
- Commissioning using cosmic muons, and integrated calibration systems
- Recently:
  - **M6**: 3-10 April 08, all subdetectors
  - **CaloWeek:** monthly, Calorimeters (LAr and Tile), and trigger (L1Calo). Results shown here from 31 March – 7 April
  - **M7** (now and on-going, all subdetectors)
- Technical Runs of Trigger/Data Acquisition (TDAQ) system: Full rate of 40 MHz



Current LHC Start-Up Schedule

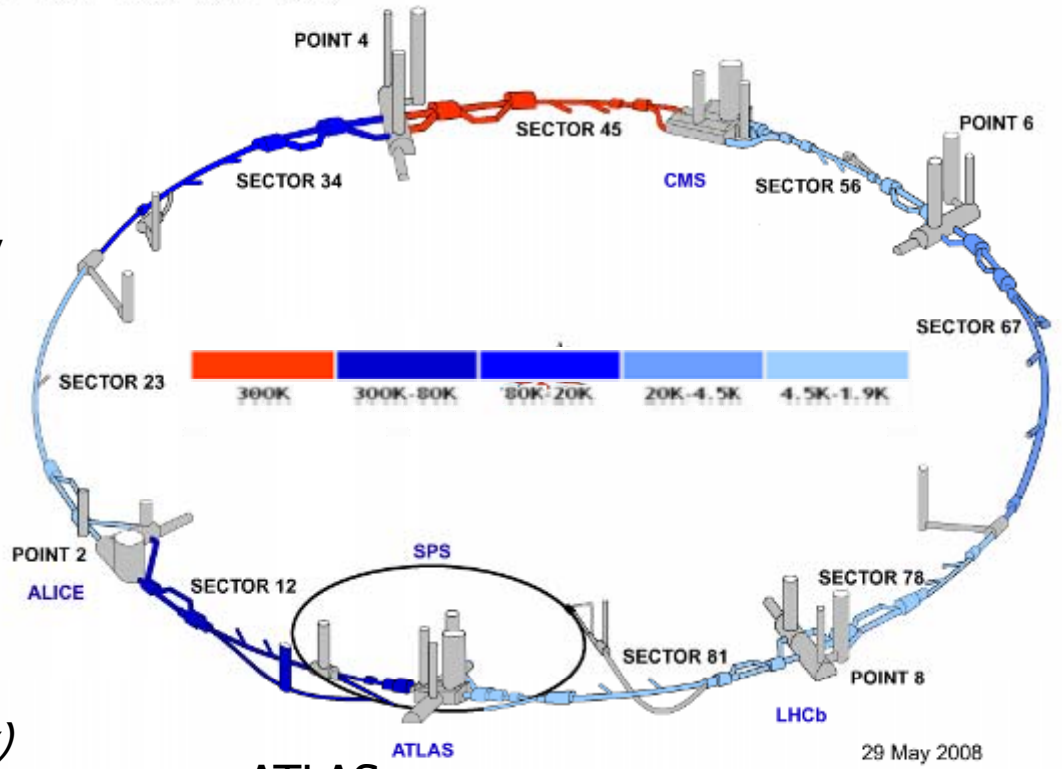
http://lhc.web.cern.ch/lhc

29 May 08

- ATLAS closes mid-July

- LHC currently cooling
- LHC startup:
  - First particles in LHC end-July
  - Aiming for first high-energy pp-Collisions by September (at 10 TeV)
  - Planning for a few weeks of stable operation in 2008 which could produce a few pb^{-1}

(Talk S8.2 by Peter Limon on Saturday)



ATLAS

Detector components

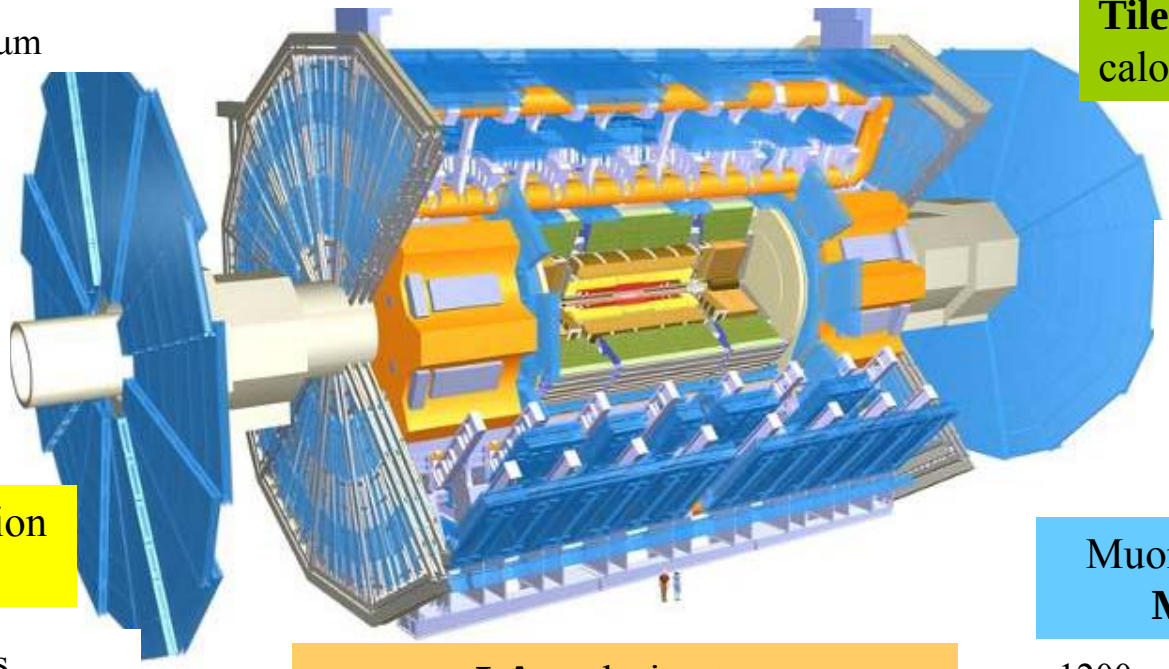
Silicon **Pixel** detector

$1.4 \cdot 10^8$ channels, intrinsic resolution 10 x 110 µm

4 super-conducting magnets: solenoid + 3 toroids

Solenoid field 2T in inner detector region

toroid field peak strength 0.4T



TileCal hadronic calorimeter (Barrel)

Sandwich structure: iron absorber + scintillator tiles

~ 10000 channels

Silicon tracker - **SCT**

~ $6 \cdot 10^6$ channels

80µm wide strips

Transition Radiation Tracker - **TRT**

Xe-filled straw tubes, interleafed with PP/PE foil

Electron - pion separation

~ 35 hits/track for track reconstruction

LAr calorimeters (EM Calo, Had. EndCap)

~ 180000 + 10000 channels (EMC,HC)

10%/√E energy resolution for e,γ

Trigger for electrons, photons and jets

Muon spectrometer **MDT, CSC**

~1200 precision chambers for track reconstruction

~600 RPC and ~3600 TGC trigger chambers

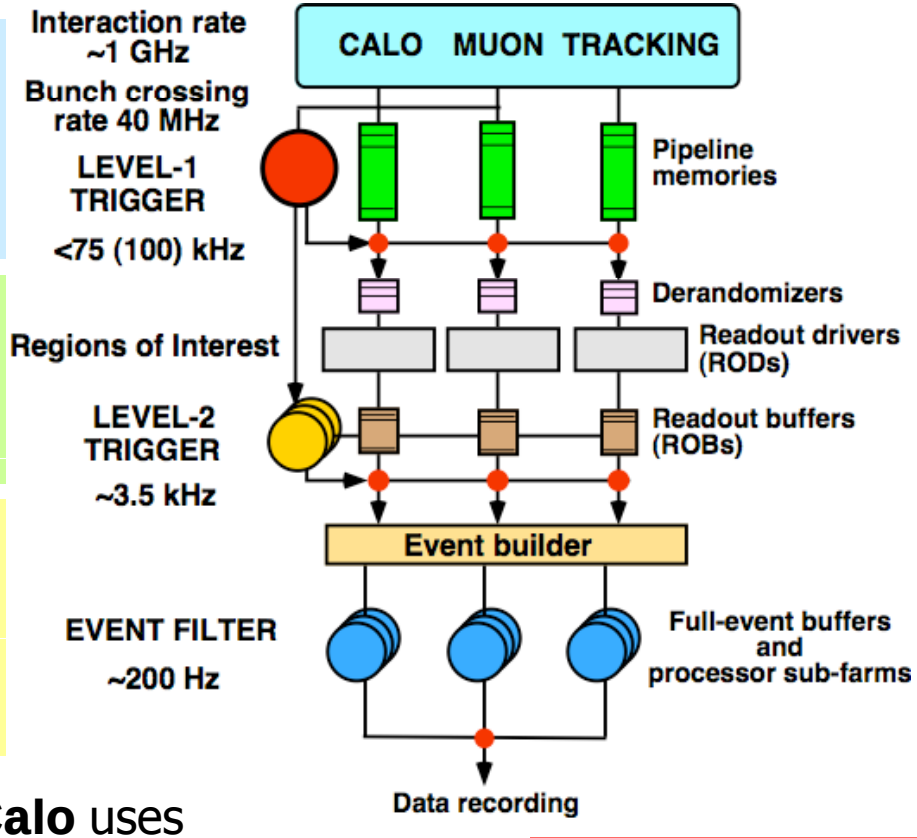
Stand-alone momentum resolution $\Delta pt/pt < 10\%$ up to 1 TeV

Trigger/DAQ architecture

Level-1 Trigger
Custom Pipelined Hardware

Region of Interest Builder
Custom Hardware

High-Level Trigger
Large PC farm
High data bandwidth
Dedicated 'Data' Network



Detector Front End Electronics
(Detector responsibility)
Detector RODs

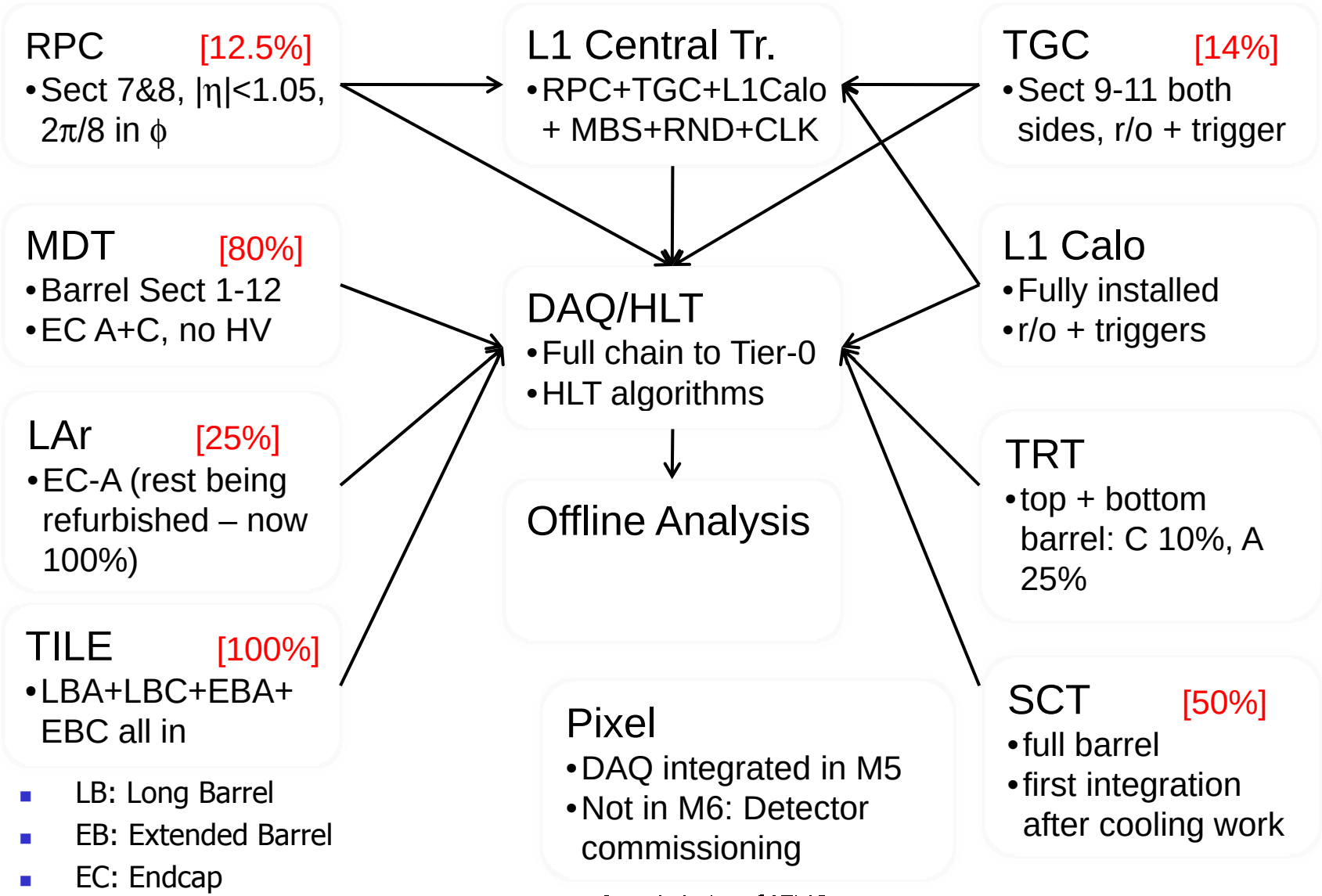
Readout System
Custom built buffers in ROS PC farm

Event Building
More PC farms
on 'data' network

- Level-1 Trigger: **Calo** uses calorimeter towers, **Muon** has dedicated trigger chambers inside muon spectrometer (RPC in barrel, TGC in endcap)

- DAQ software – control, configuration, monitoring (control network)

M6 setup (April): Detector Coverage



- LB: Long Barrel
- EB: Extended Barrel
- EC: Endcap
- A or C: which side

Calorimetry

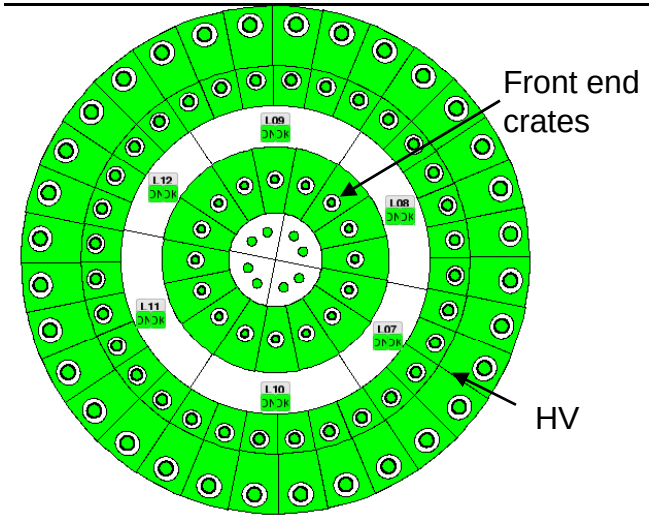
Calorimeter Commissioning: LAr

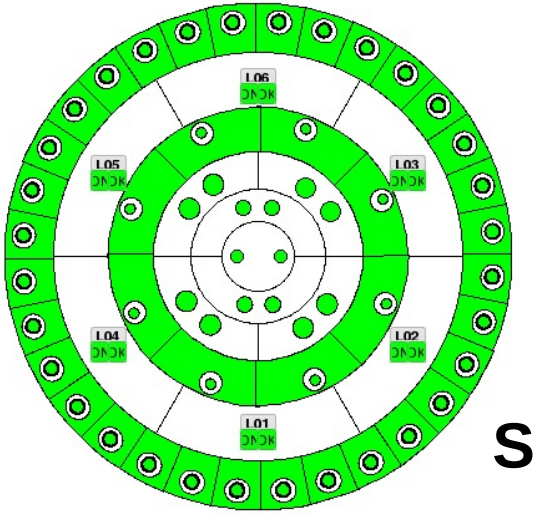
- M6 April '08: Only EndCap A participating
  - EndCap C was being filled with LAr
  - Barrel: refurbishment of front end boards going on at that time
- CaloWeek April '08:
  - HV switched on (nominal HV) for the full LAr system
  - First muon runs with the full LAr calorimeter at nominal HV
  - Cosmic muon data taking in 32 sample transparent mode (nights and weekend) and test in 5 sample physics mode
  - Timing with respect to Level-1 Calo and Tile trigger
  - Monitoring, DQ tools, HLT studies
- M7 May '08:
  - Running with full LAr calorimeter system, 100% read-out and working as expected

Status of LAr Calorimeter System

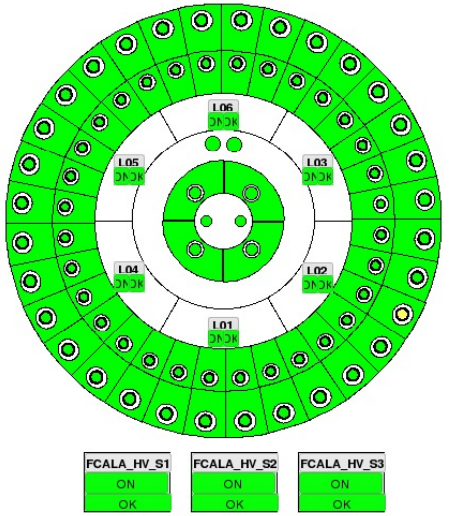
- 100% of the detector switched on, participating at April CaloWeek data taking (HV, LV, …). Remaining crate operational since Friday 2nd May.

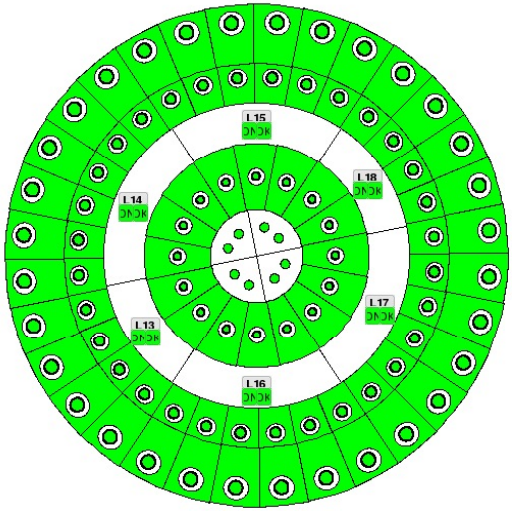
EM Barrel Cal. **EM-EndCap Cal.** **Had. EndCap & Forward Cal.**

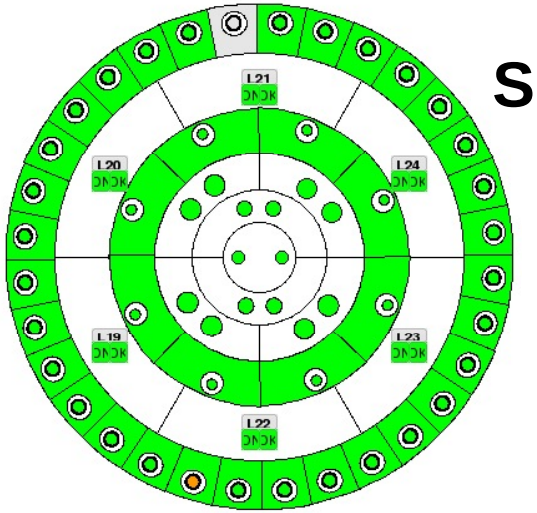




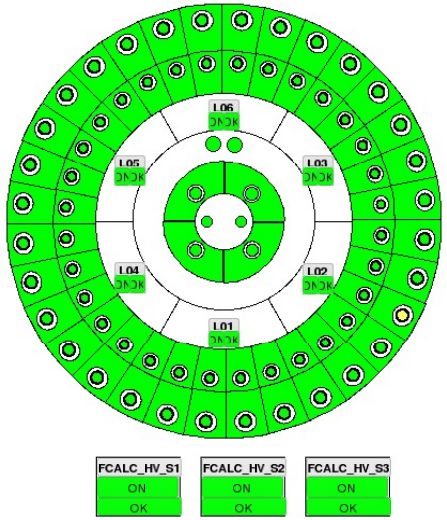
Side A





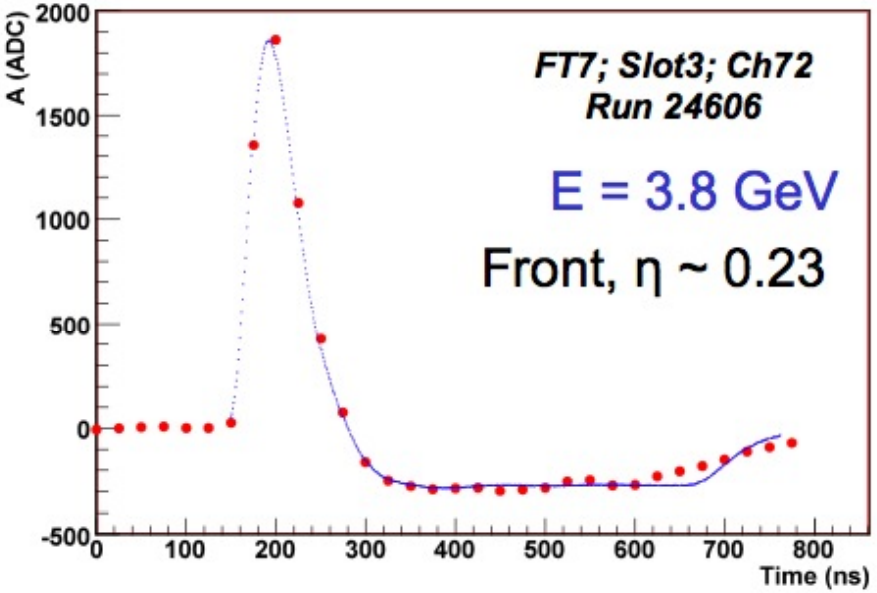


Side C

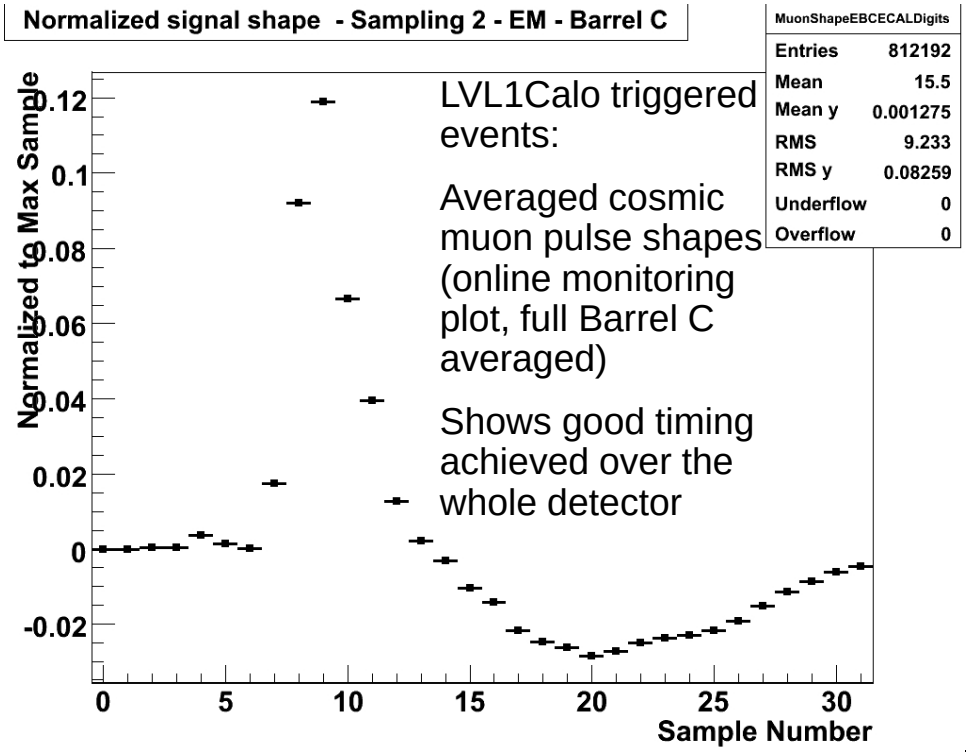


LAr: Analysis of Cosmics from April CaloWeek

- First data taking with the full LAr detector (100% since 2nd May)
- Many quantities available in the online monitoring:
  - Digits, Noise, Timing, Cells, Clusters



Single cosmic muon pulses fitting very well to the predicted pulse shape

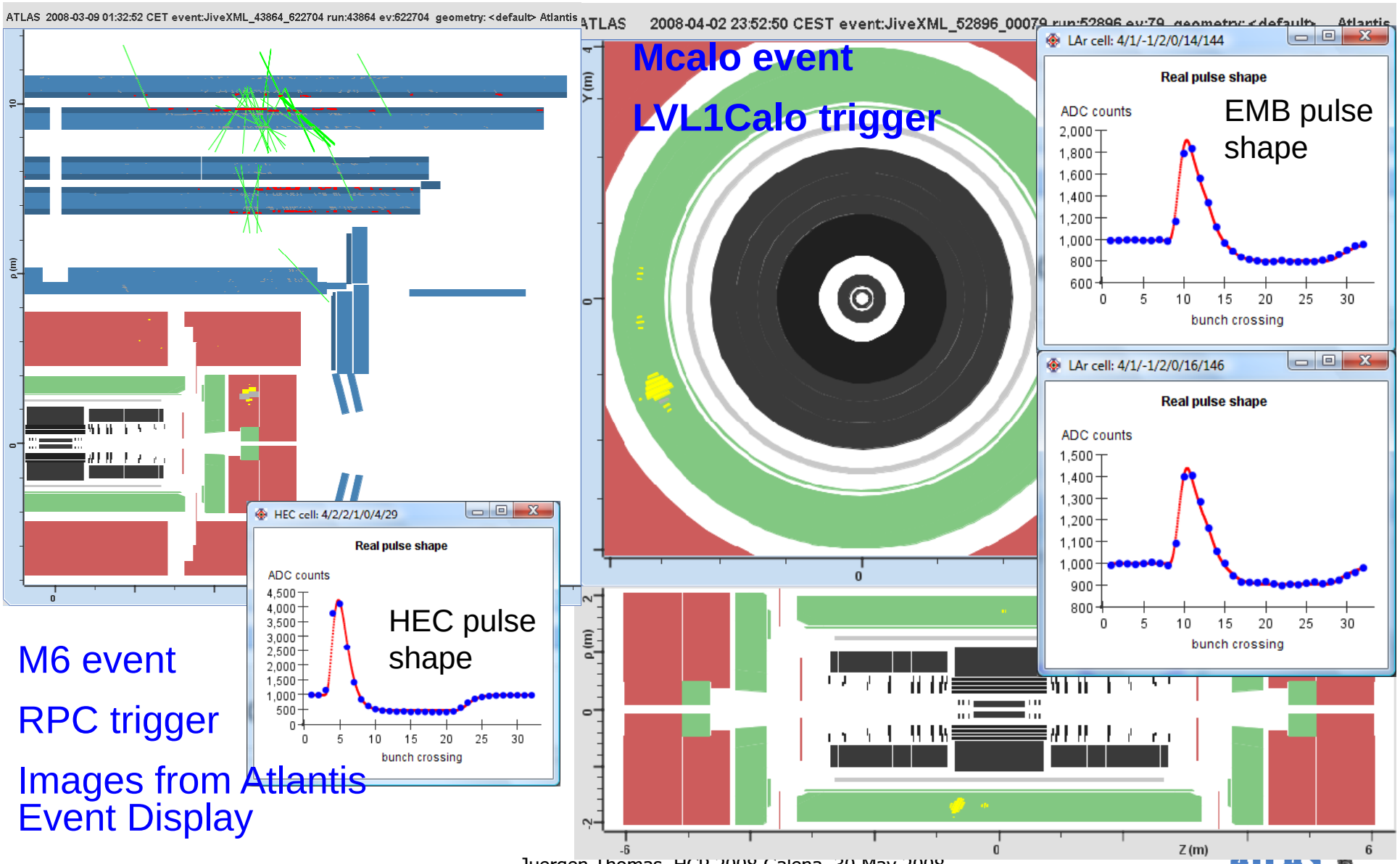


LVL1Calo triggered events:

Averaged cosmic muon pulse shapes (online monitoring plot, full Barrel C averaged)

Shows good timing achieved over the whole detector

Event Displays from M6 and CaloWeek

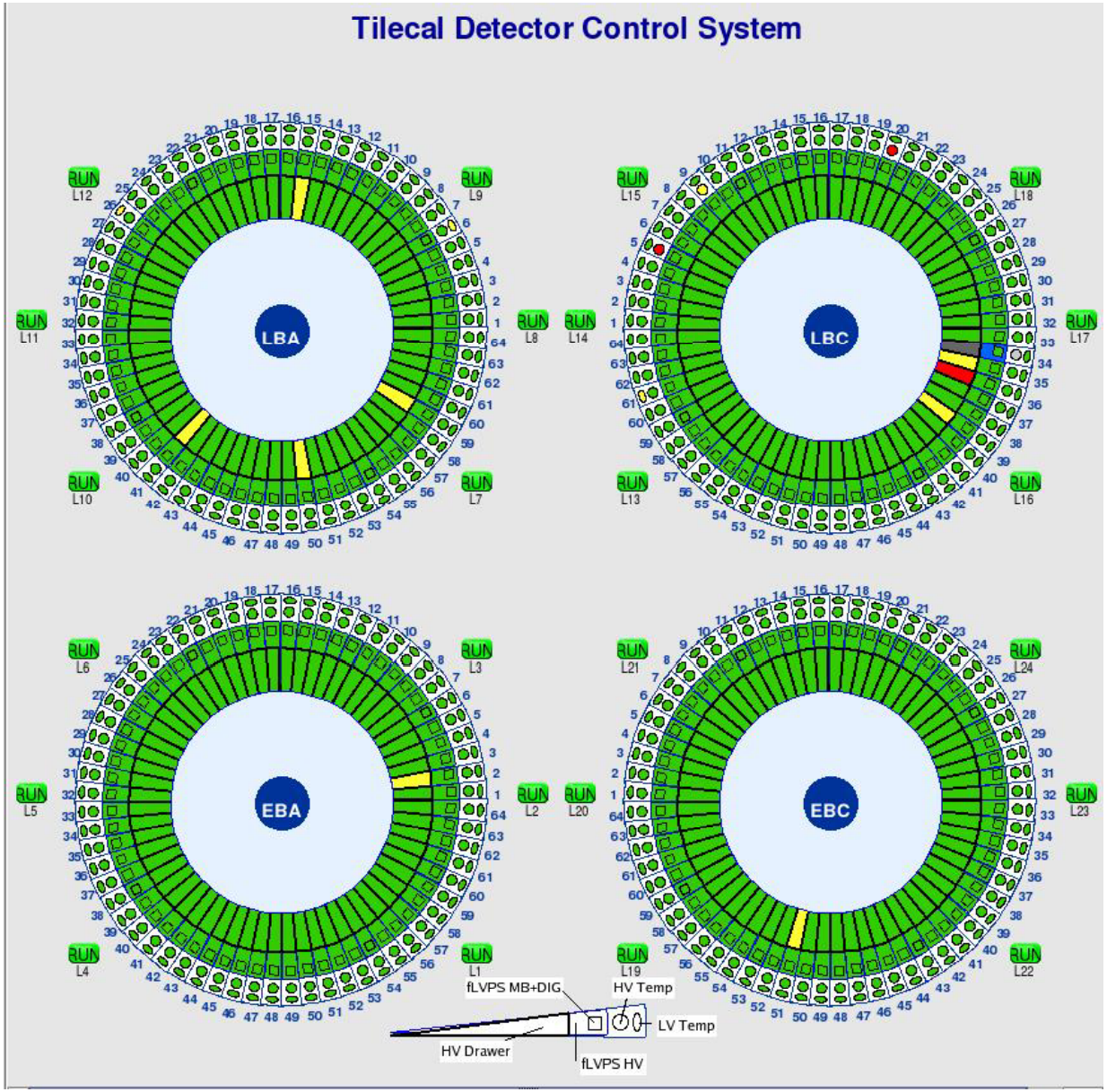


M6 event

RPC trigger

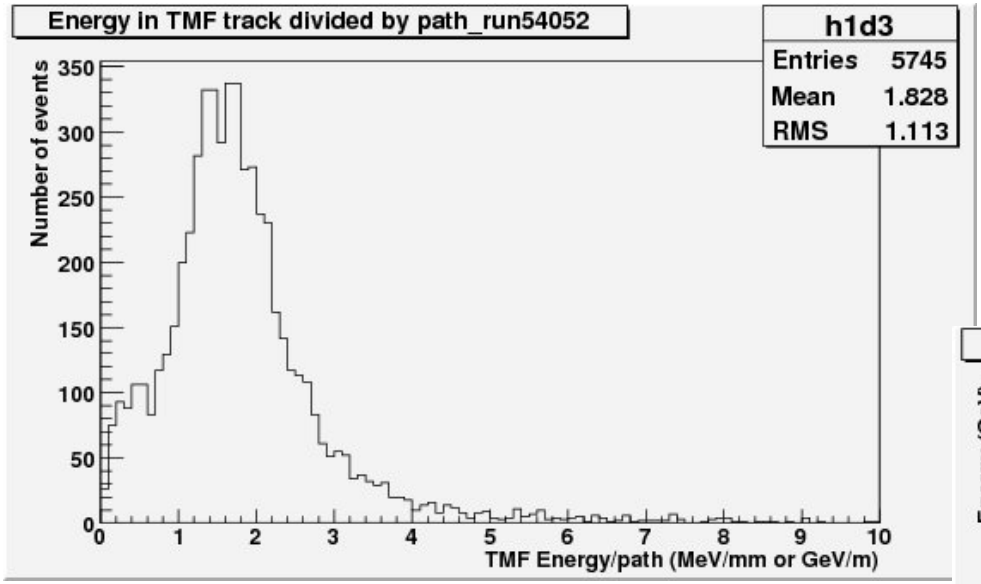
Images from Atlantis Event Display

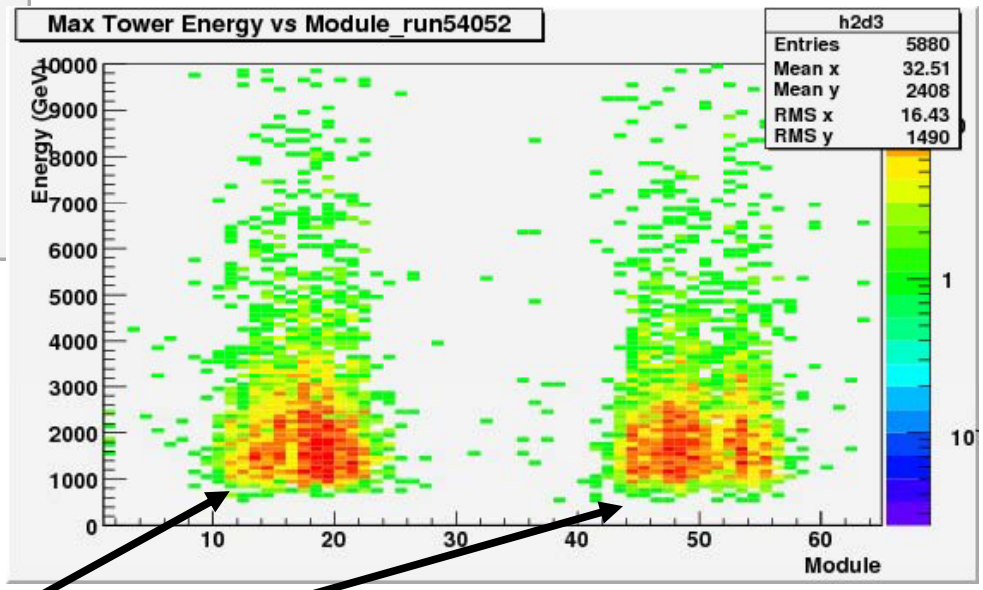
Tile Cal: Coverage



- Almost full coverage (Image shows status 15th May):
  - 95% barrel
  - Some modules still in refurbishment (power supply)

Tile Cal: Energy in Calo Week (April)

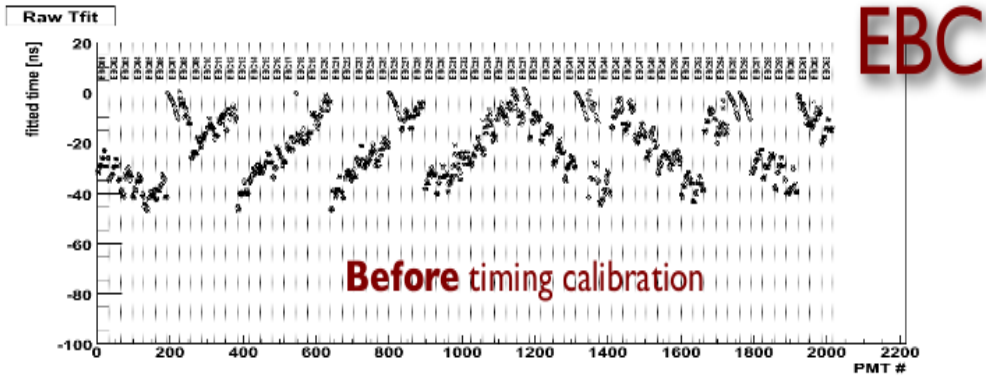


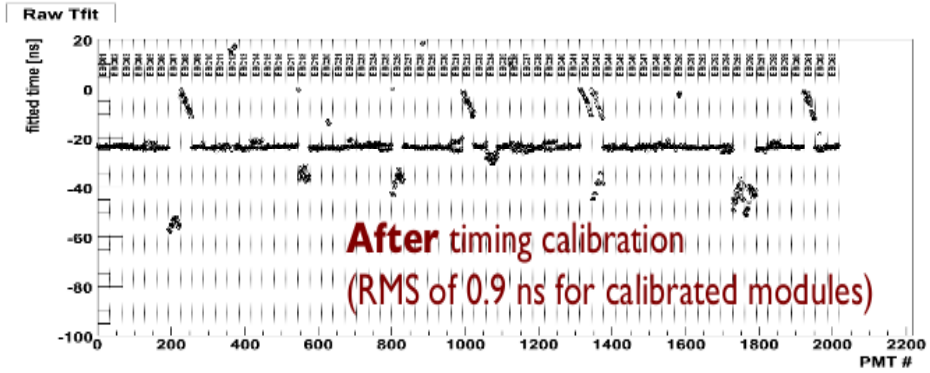


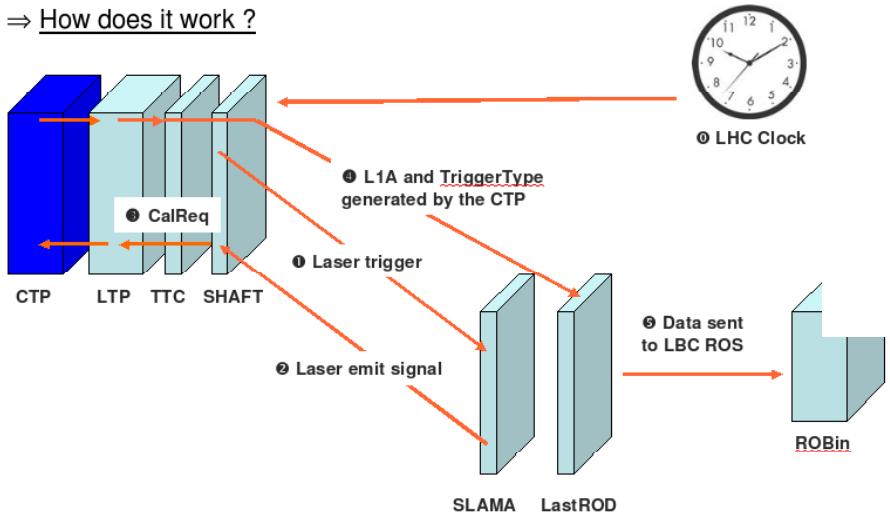
- Good energy density peak
- No top-bottom bias:
  - ϕ segmented into modules 1-64
  - cosmics muon depositing similar energies passing top (module 17/18) to bottom (module 48/49)

Tile: Laser Calibration System

- Commissioning of Laser system is in advanced state.
- Laser used routinely in commissioning data taking to send light to PMTs
- Laser data essential for timing intercalibration of TileCal readout.
- Tests with CTP and TDAQ done in January
- Work ongoing in order to integrate laser with Online and DCS monitoring





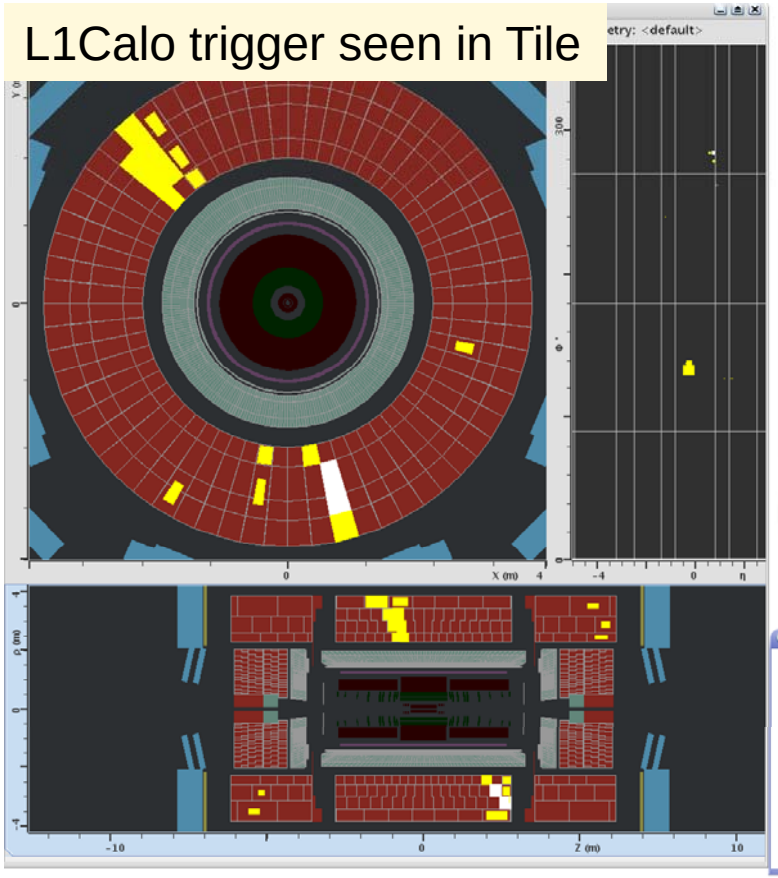


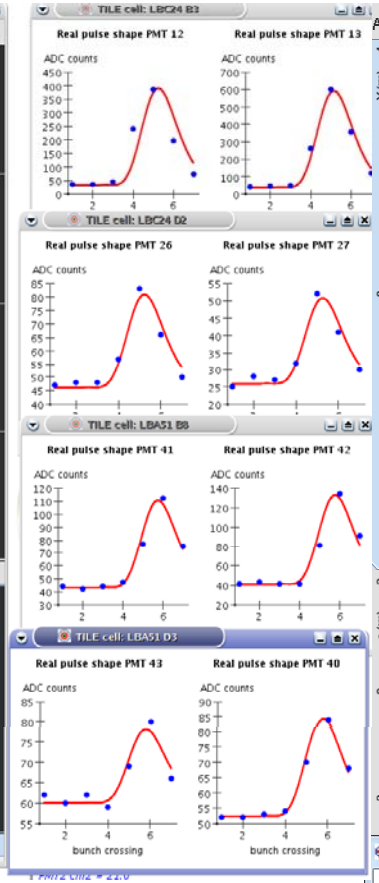
Laser pump

Patch panel

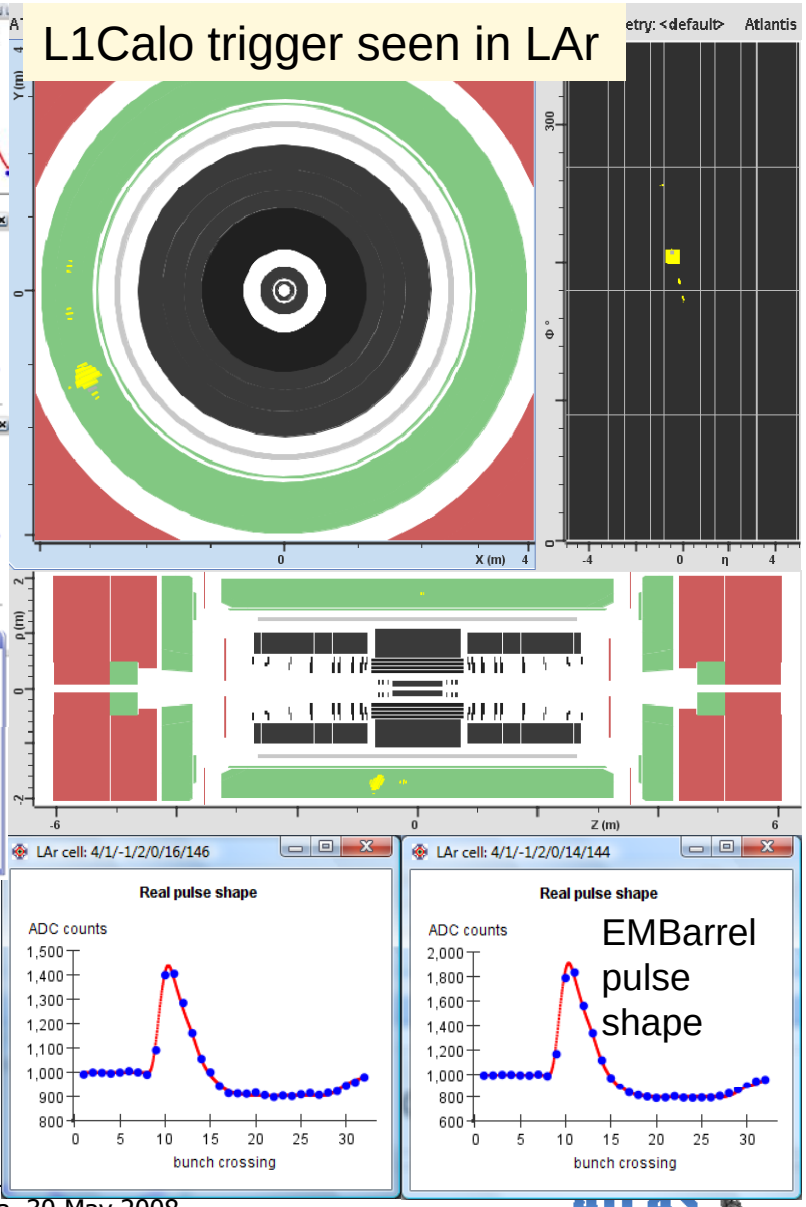
Calorimeter commissioning

L1Calo trigger seen in Tile





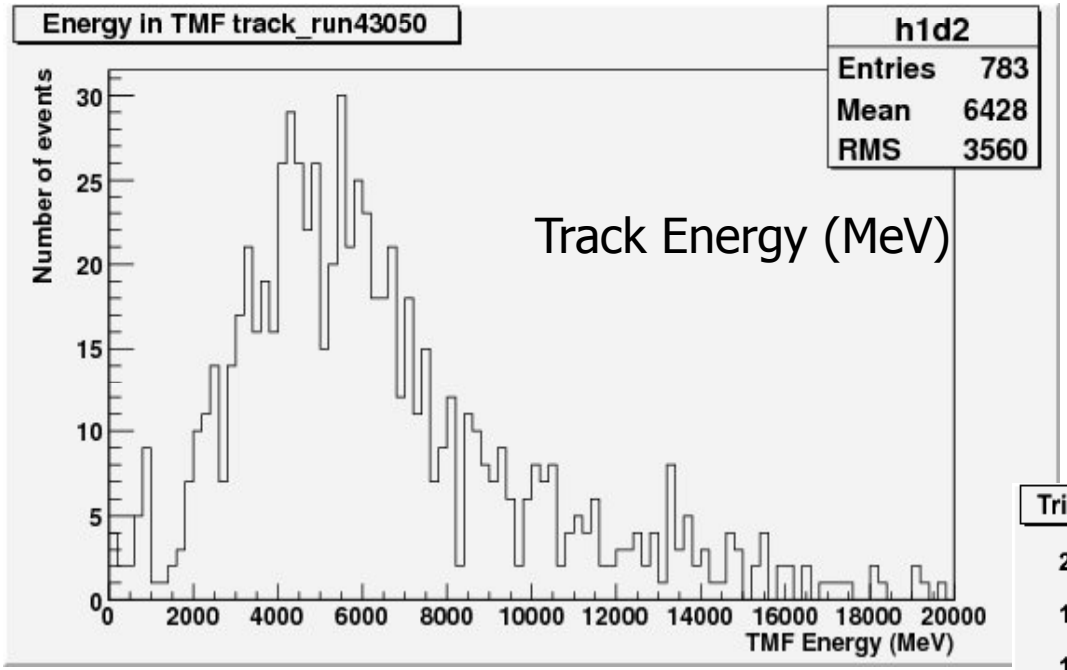
L1Calo trigger seen in LAr



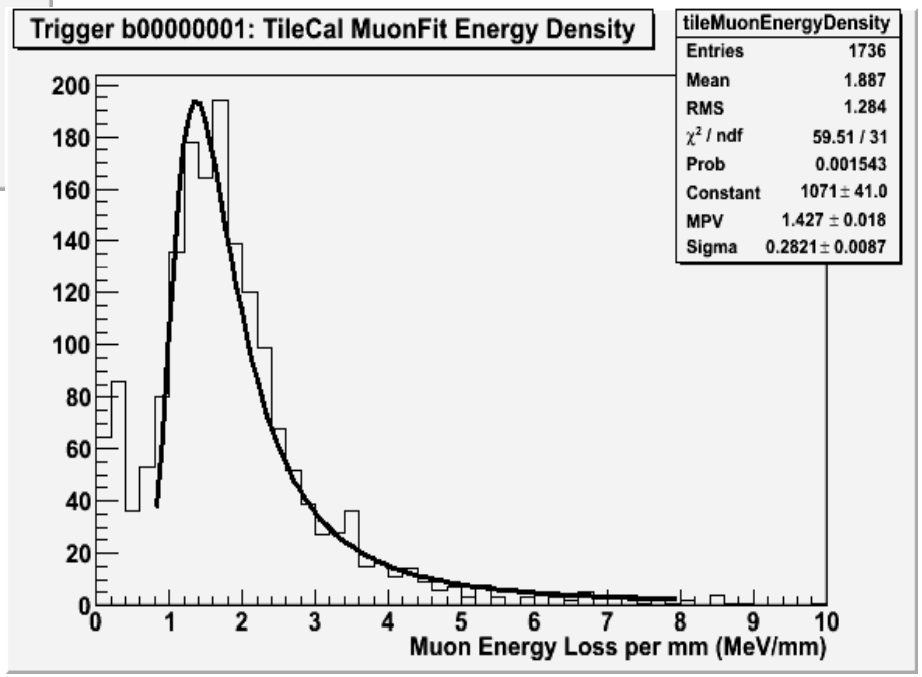
ADC counts vs. bunch crossing

Extensive testing of Calorimeters and L1Calo during M6 and after, including trigger timing studies

Cosmic data analysis: Tile Calorimeter



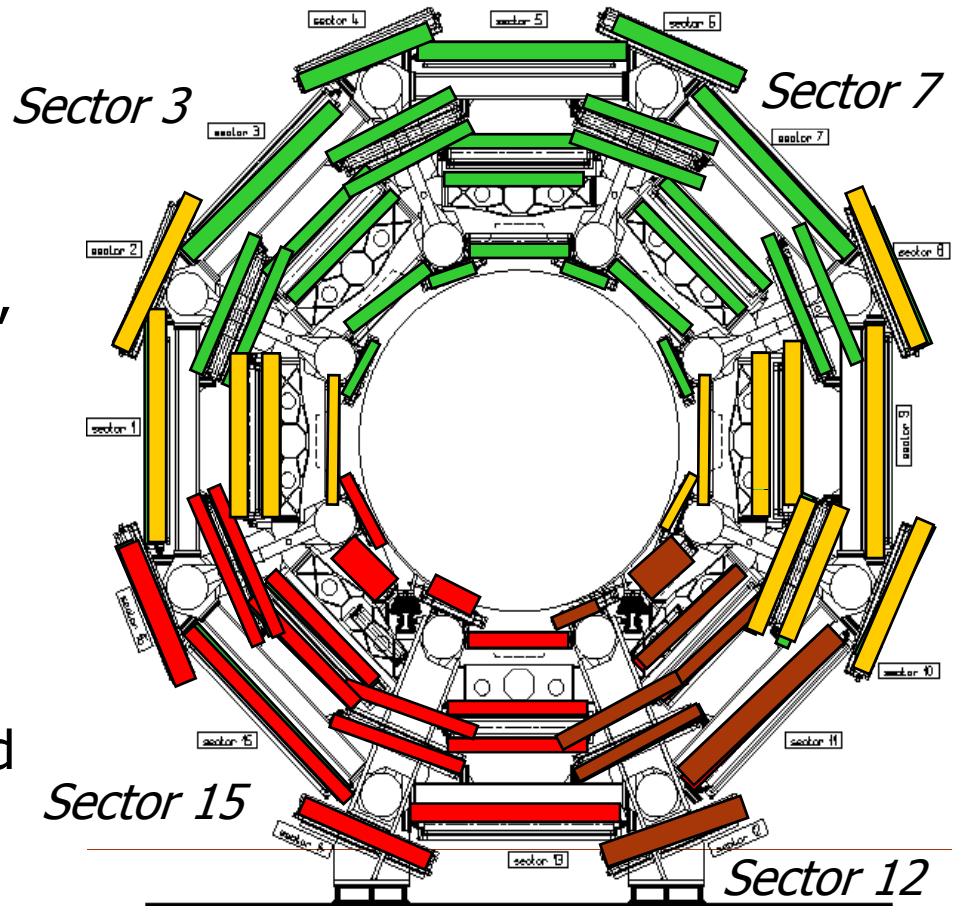
TileMuonFitter:
Building track-like objects from Tile calorimeter data (new versions, less sensitive to noise)



Muon Detectors

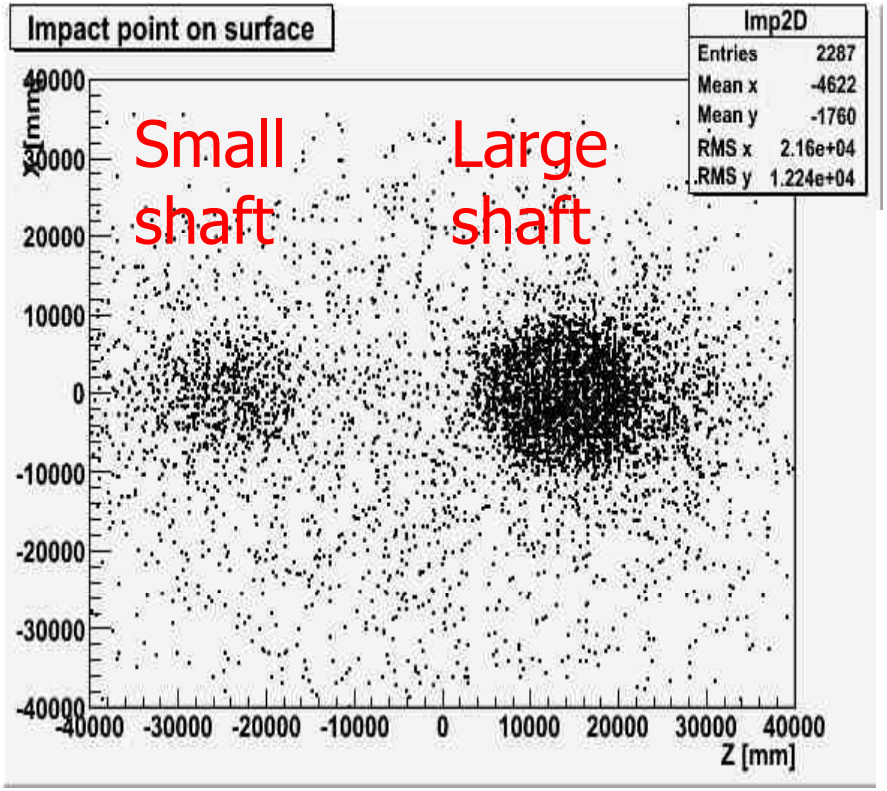
Muon Barrel Commissioning: Sectors

- Muon Spectrometer Barrel (MDT):
  - Consists of 16 sectors
  - LV power on in all barrel sectors, early all chambers
  - HV power on, apart from lower sectors (supplies)
  - Sectors from 3 to 8 commissioned with Cosmic rays
  - Sectors 11-12 under test
  - Many problems found and solved
  - Installation issues: Access for other detectors

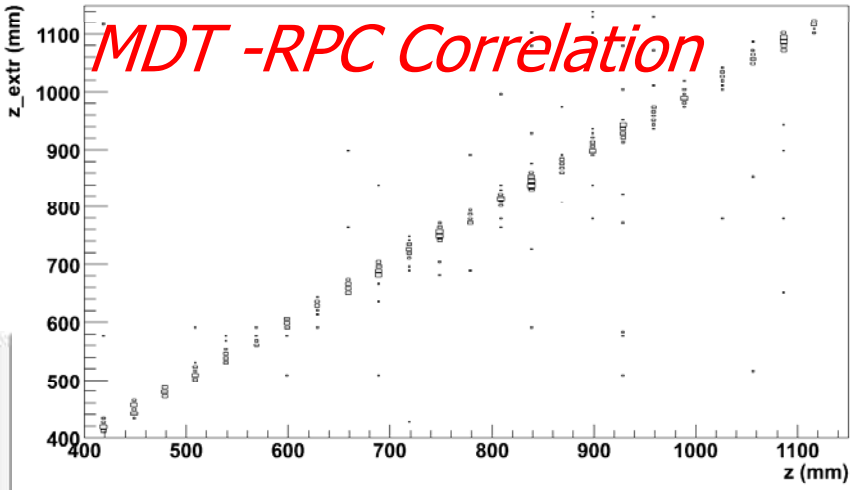


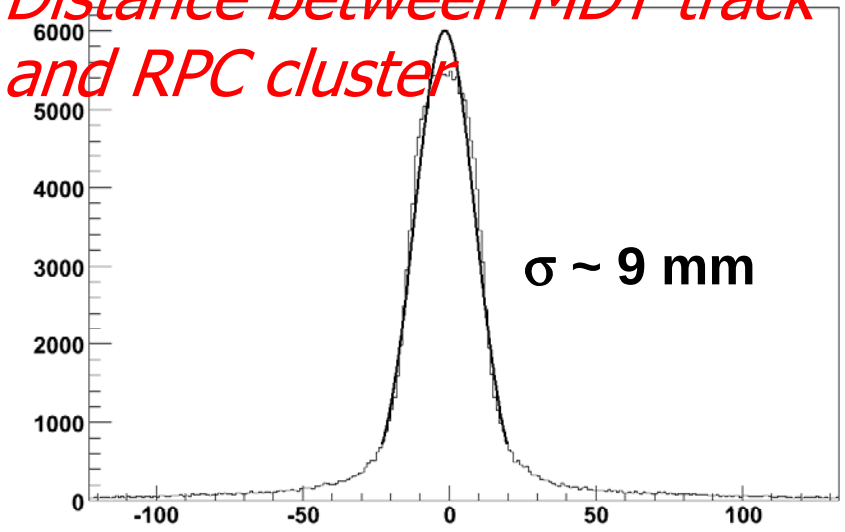
Muon Barrel Sector Commissioning: RPC

RPC (Level-1 Muon Trigger):
Standalone Tracking:
Triggered Cosmic Rays impact point at surface

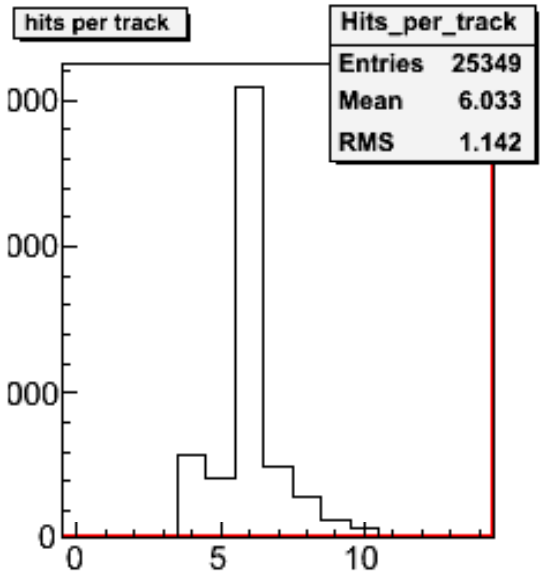


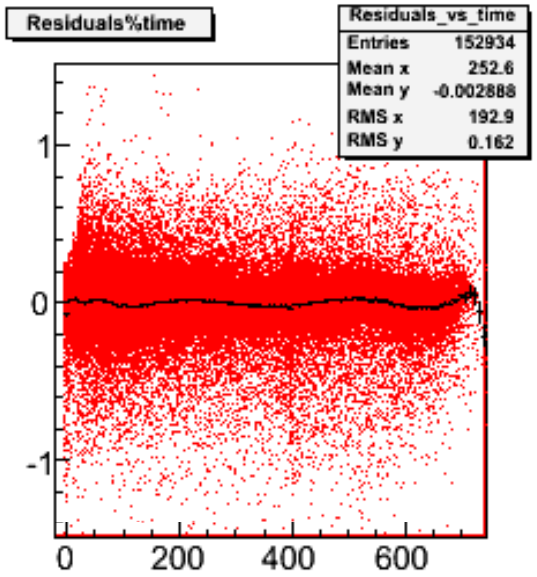
(Shafts into ATLAS cavern)

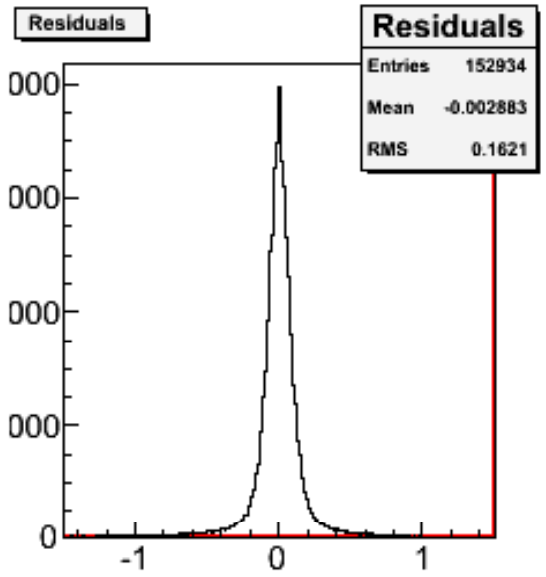


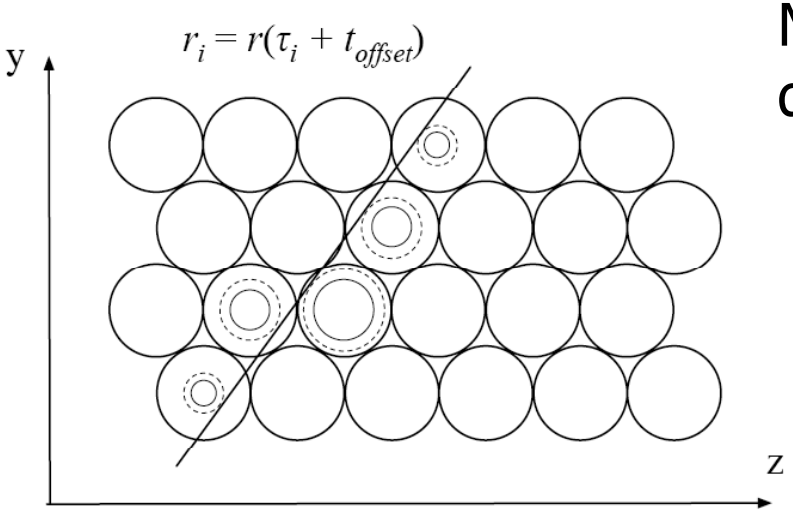


Muon Barrel Sector commissioning: MDT Results







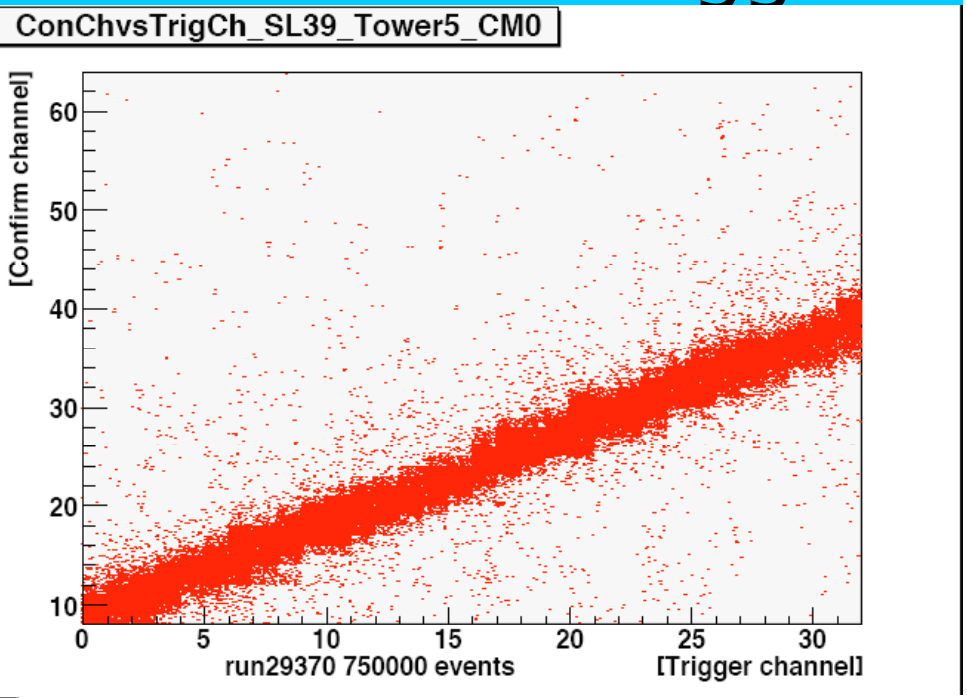


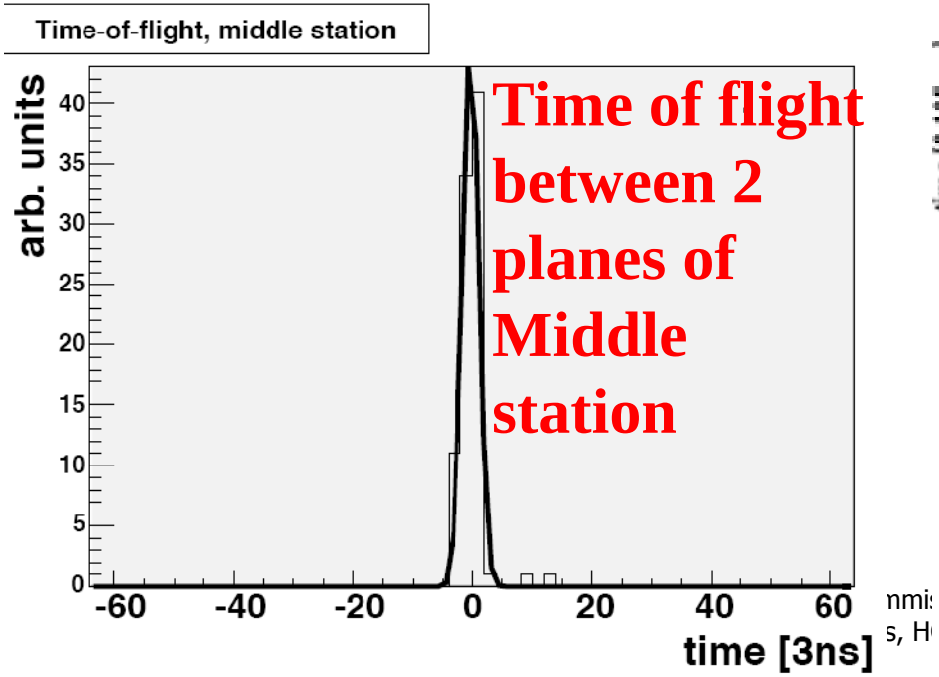
MDT shows very good track quality for cosmics:

- 6 hits per track
- Residuals centered at 0
- Residuals RMS ~160 μm

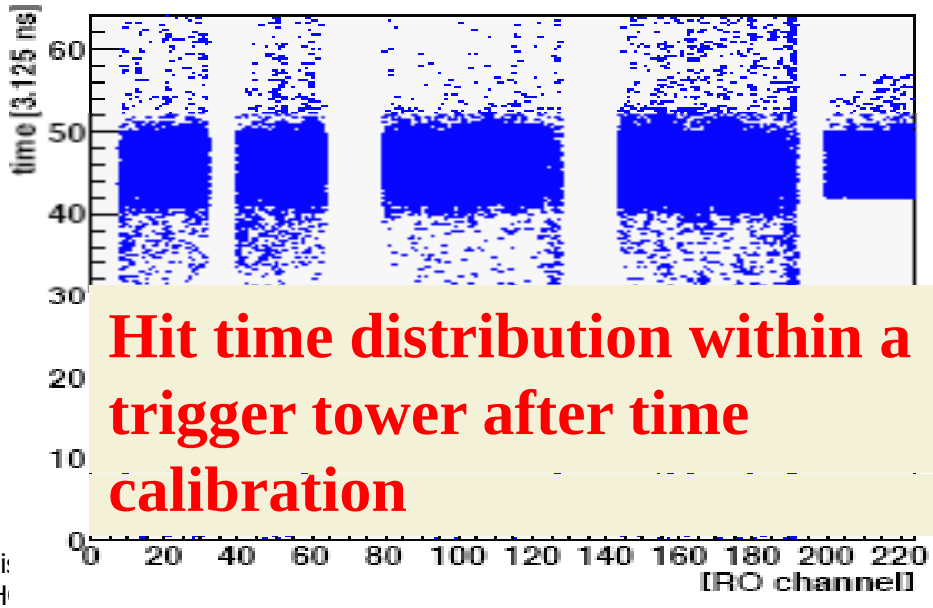
Barrel Commissioning: Level-1 Muon Trigger

- Check of the trigger road settings: Width of correlation band between clusters on middle layer RPCs corresponds to the trigger road
- Trigger time Calibration: Fit the time of flight distribution between 2 planes and derive the time offset per layer





Time of flight between 2 planes of Middle station



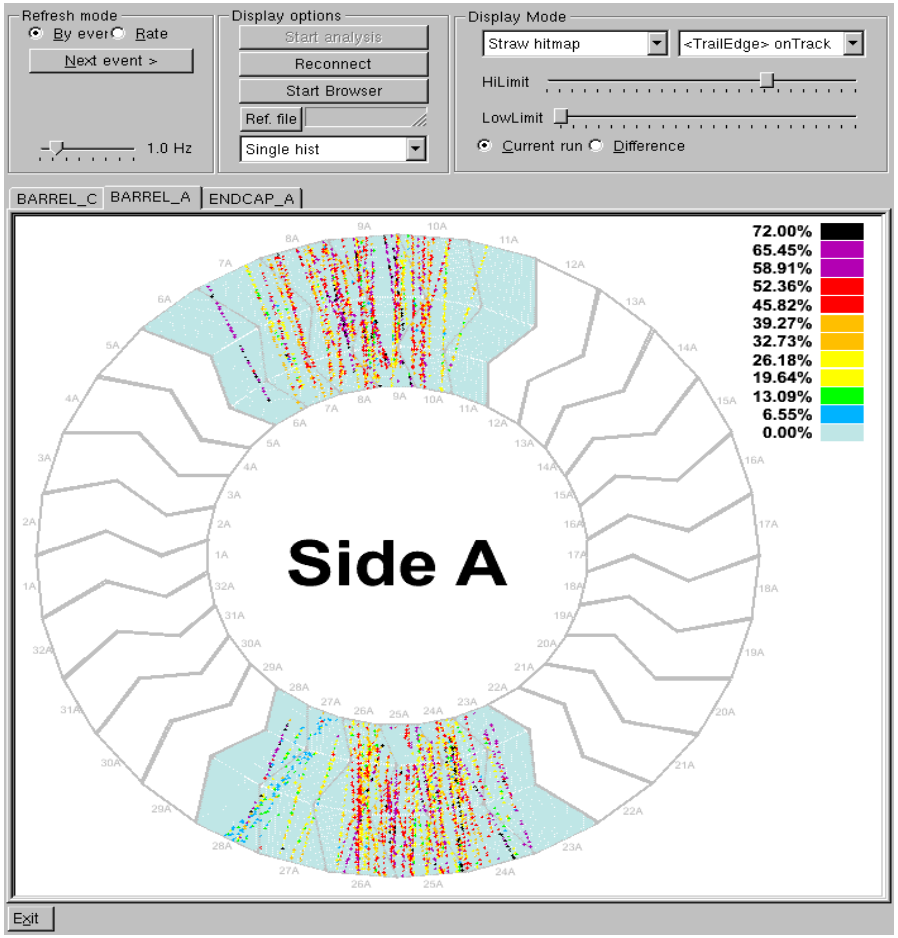
Hit time distribution within a trigger tower after time calibration

Inner Tracking Detectors

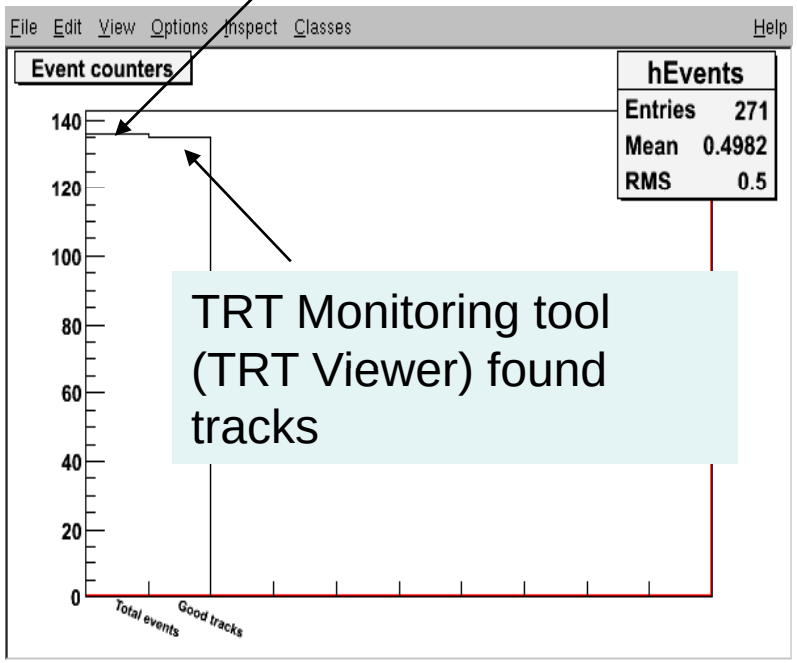
Inner Detector Installation Status

- Inner detector consists of: Pixel, SCT, TRT
- Commissioning of the Pixel and SCT had major setback on 1 May, due to break-down of compressors for the evaporative cooling system after only 5 days of testing of Pixel detector
- Compressors have been dismantled and are being repaired
- The failure resulted in contamination of coolant (C3F8) and entire cooling plant must be cleaned before cooling can be restarted.
- Cleaning, repair, and restarting of cooling plant will take until at least mid-June.
- Bakeout of central section of beam pipe in ATLAS requires cooling plant to be operational, and at least innermost layer (plus some disks) of Pixels detector to be cooled
- This failure means that Pixel sign off tests before closing ATLAS were severely reduced, and has major impact on SCT and Pixel commissioning time

TRT: Event in Barrel and End-Cap-A



Events with L2 tracks

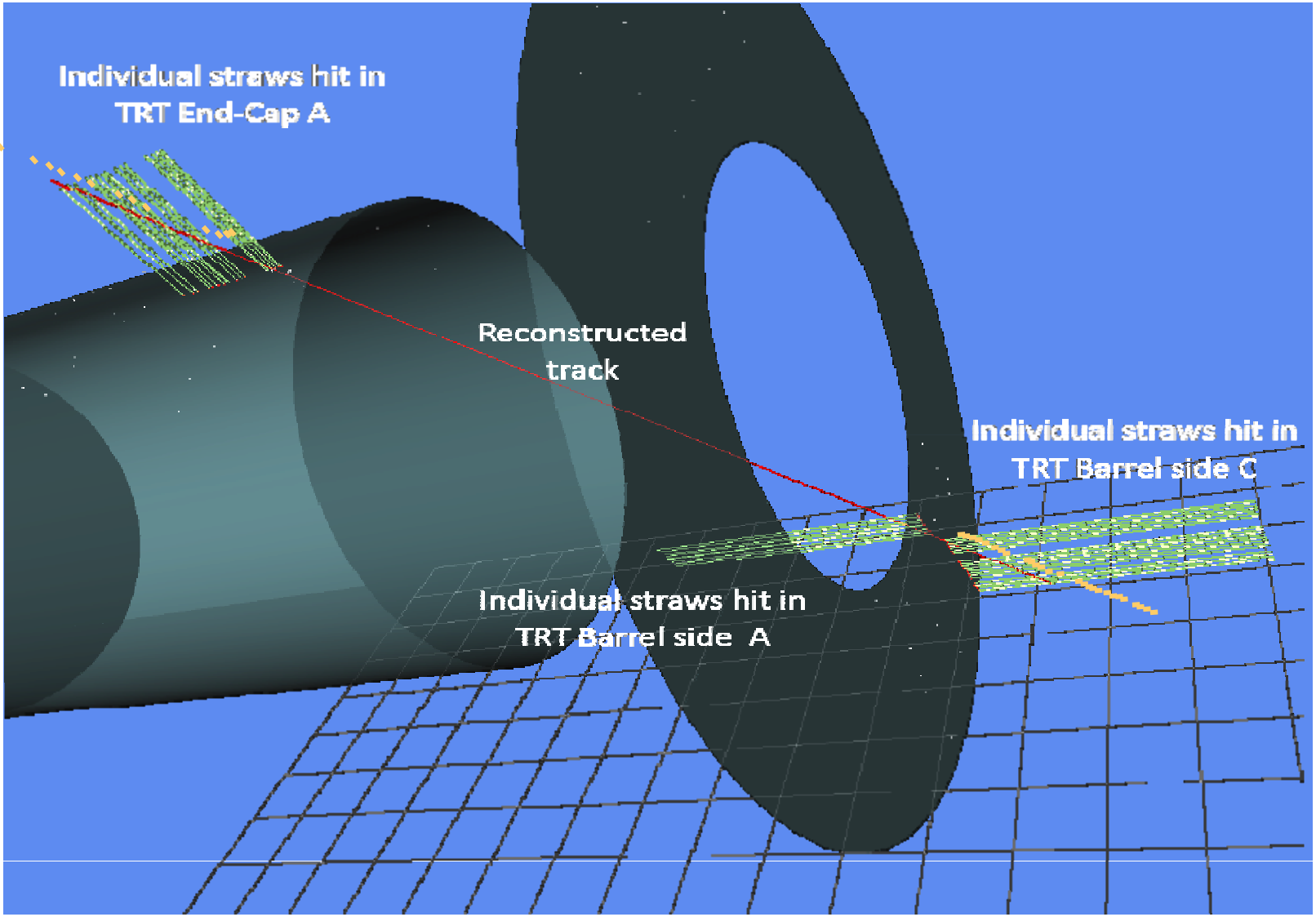


TRT Monitoring tool (TRT Viewer) found tracks

- Efficiency of the L2 tracks with respect to TRT monitoring tool

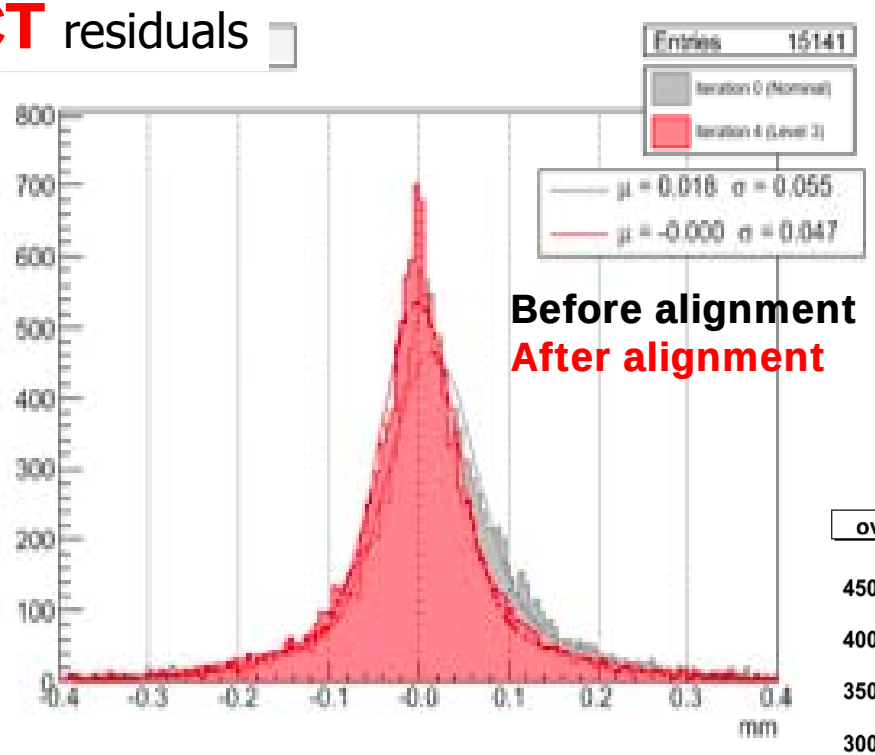
Trigger from scintillation counter (2ns jitter) and tile calorimeter

TRT: Event in Barrel and End-CapA



Cosmic data analysis: TRT and SCT

SCT residuals

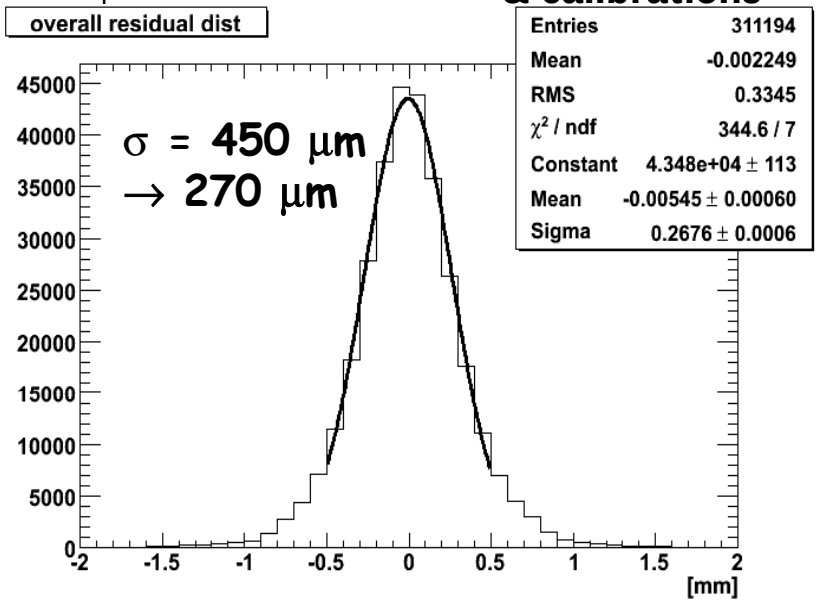


Before alignment

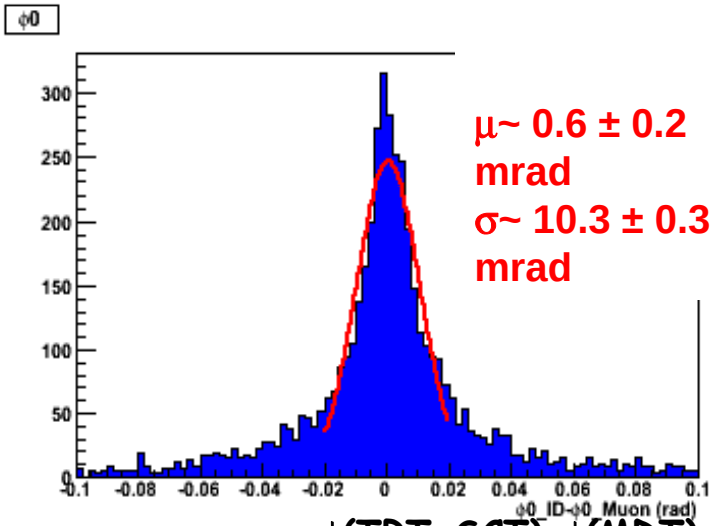
After alignment

TRT residuals

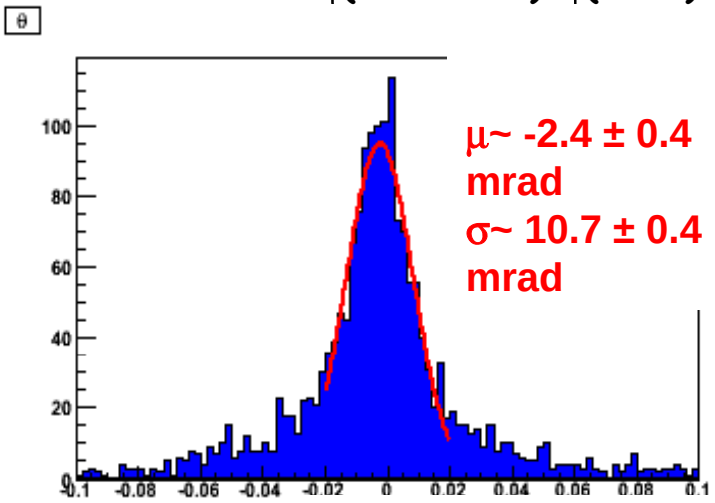
After alignment & calibrations



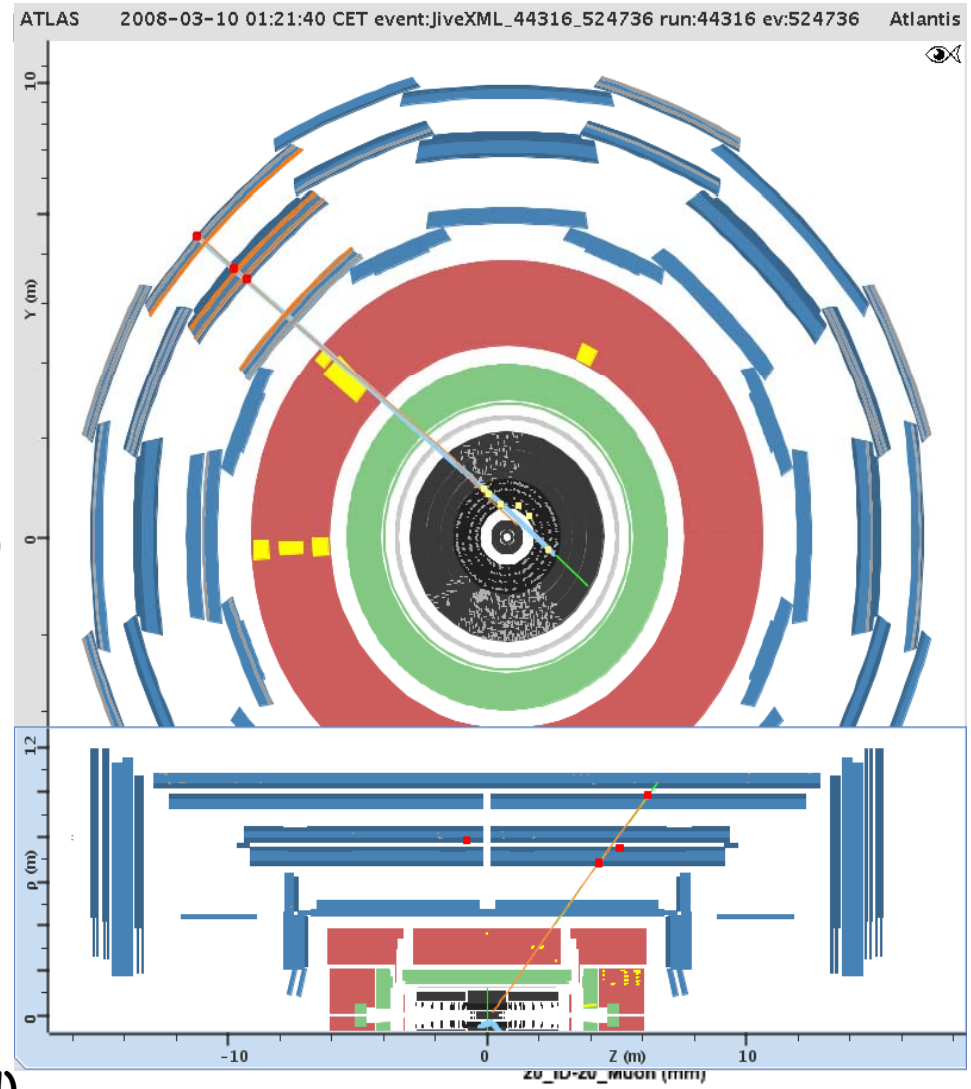
Cosmic data analysis: TRT+SCT and Muon



φ(TRT+SCT)-φ(MDT) (rad)



θ(TRT+SCT)- θ(MDT) (rad)

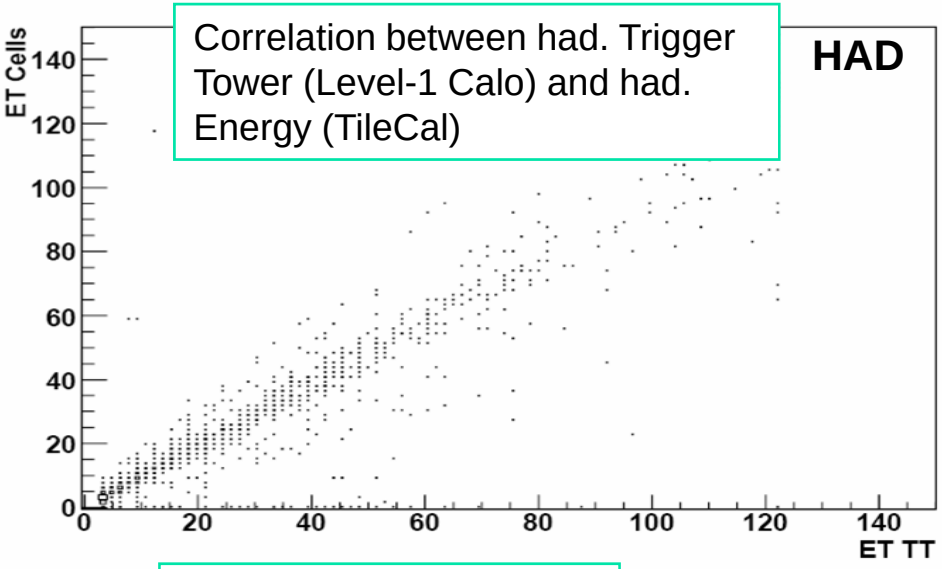


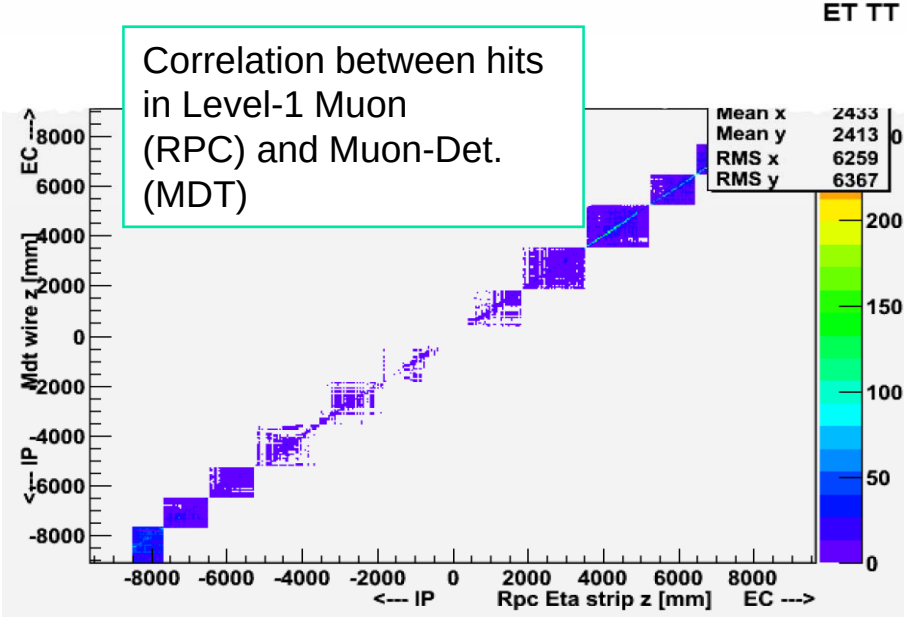
Difference of track position (η,φ) TRT+SCT vs. Muon (MDT)

Trigger and Data Acquisition (TDAQ)

Level-1 Trigger Commissioning

- Calorimeter trigger signals are thoroughly tested before access disappears
- Muon trigger commissioning done sector by sector (Availability of gas and power supplies)
- Timing being addressed
  - Require all triggers to have same timing w.r.t. (non-existent) bunch-crossing
  - Complete system needs to be available (Calo and Muon)



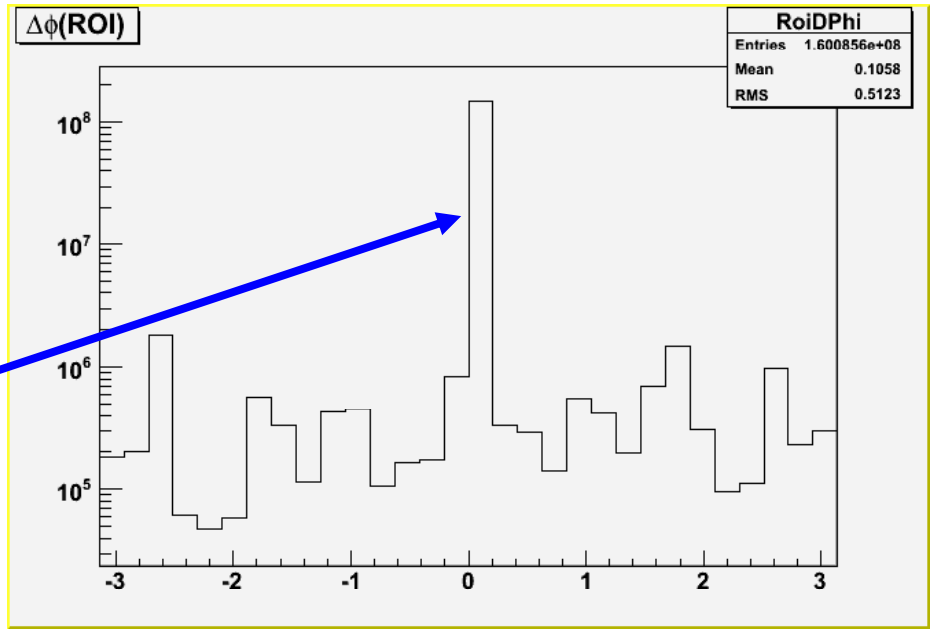


Level-1 Calo Triggering in April CaloWeek

- Setup for combined running:
  - L1Calo, LAr, Tile
  - TDAQ
- Triggering on (in collisions):
  - electron/gamma trigger
    - At > 5 GeV
  - jet trigger at
    - At > 20 GeV
  - tau trigger at
    - At > 15 GeV
- Regions
  - LAr: EM-Barrel, EM-Endcap (EMEC), Had. Endcap (HEC)
  - Tile: Barrel, Extended-Barrel
- Spacial correlation (dϕ) of interesting regions flagged by L1Calo (ROI) compared to Calo (LAr and Tile) (in *log* scale)

CTP Items, retrieving data from: LumiBlock.LB_CTP_54046_00010

	CTP ID	Item Name	Before Prescale	After Prescale	After Veto
1	61	NIM8	14.7708	1.46875	1.46875
2	26	1EM2	1.51042	1.51042	1.44792
3	9	1J4	1.46875	1.46875	1.33333
4	10	1J5	1.02083	1.02083	0.927083
5	36	1TAU4	0.927083	0.927083	0.833333
6	63	NIM10	4.04167	0.395833	0.395833
7	53	NIM0	0.364583	0.364583	0.260417
8	62	NIM9	0.583333	0.0625	0.0625
9	27	1EM3	0.0833333	0.0833333	0.0520833
10	64	NIM11	0.145833	0.0208333	0.0208333
11	242		0	0	0



High Level Trigger Infrastructure

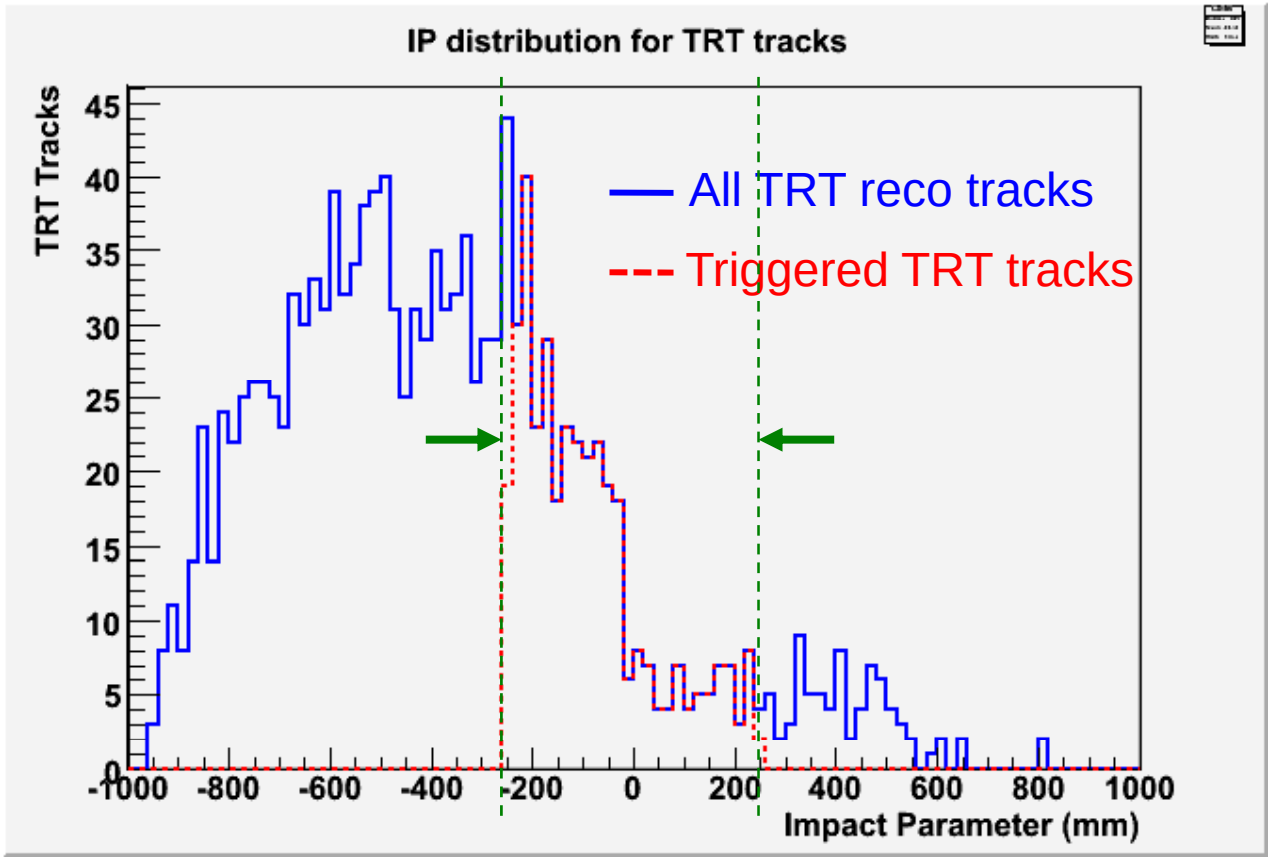
- HLT nodes consist of:
  - Level-2 Supervisors
  - Level-2 Processing Nodes
  - Event Filter Nodes
- 1U rack mounted dual quad core
- Regularly used in commissioning runs
- Expansion to 830 nodes
  - 35% of foreseen system
- Rapid installation (3 racks per week)

- Sub Farm Inputs perform Event Building on Level-2 selected events, Event building at ~3kHz (event size 1.5 Mbyte)

- Sub Farm Outputs write Event Filter-selected events to disk
  - Write to separate streams
  - 6 available (final number)
  - 300 Mbyte/s to computer centre

High Level Trigger: Track Trigger

High Level Trigger



- Analysis of one M6 cosmics commissioning run taken in March 2008
  - Trigger is requiring TRT tracks reconstructed online within pixel volume (equivalent to d0 ≤ 250 mm)
  - Triggered events (red) end up in one stream file, non-triggered events (blue) into another one: proves trigger and streaming are working

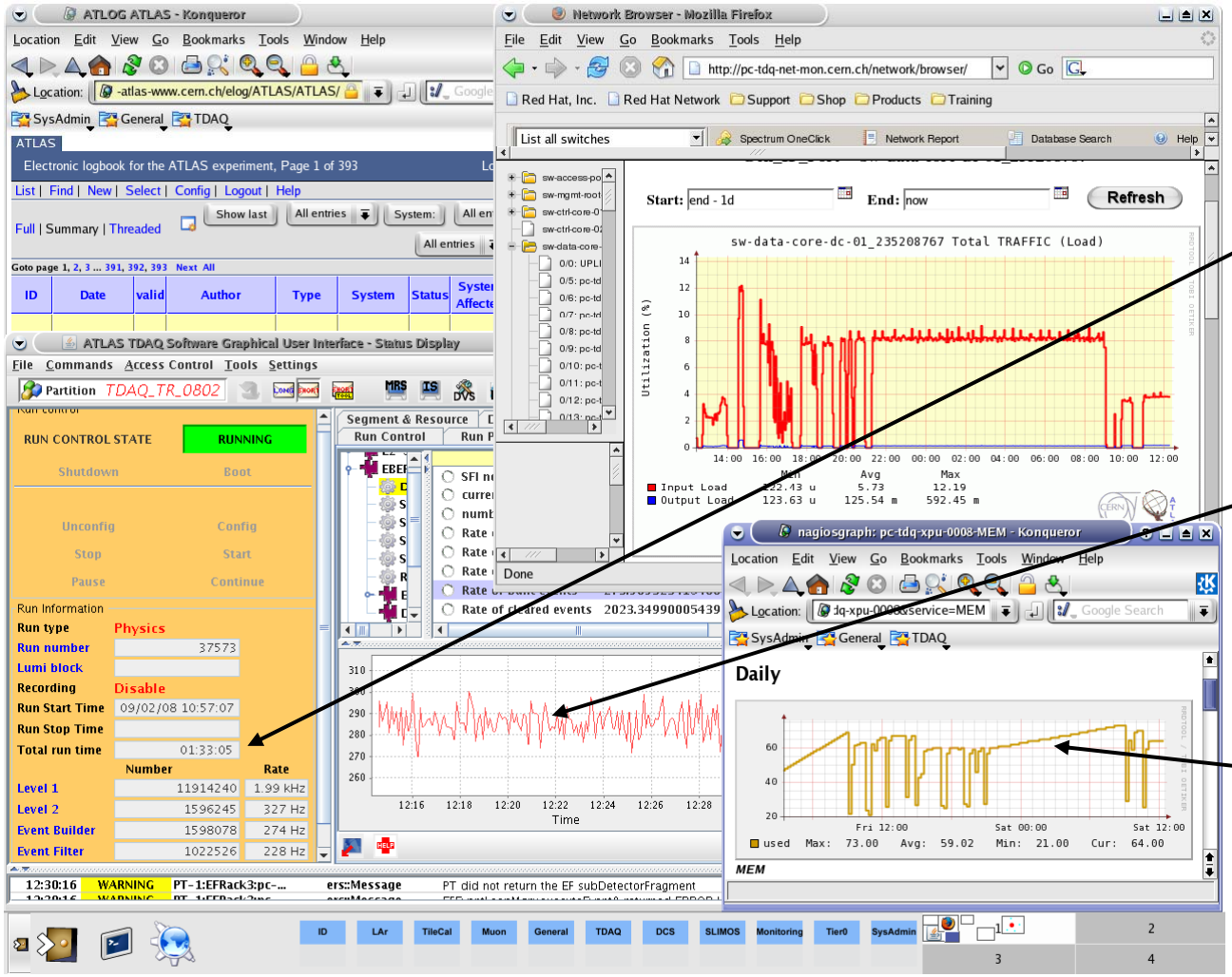
Technical Runs

- Series of tests of TDAQ-only at nominal rate (40 MHz input). Using busy events e.g. ttbar from MC.

Most recently in April '08:

- Concentration on stress tests: Stress data flow at all levels
- Achievements:
  - Stable running (several hours without intervention)
    - Event sizes from 1 MB to 10 MB
    - Event Building and Data Writing ran at Gbit link limits
  - Controlled ~1500 applications over 350 nodes
    - Successful, though some tweaks needed in error handling
  - Playback of M4, M5 and Monte Carlo data to test all algorithm slices
  - Generated data set for luminosity 10^{31} used to test HLT menu for initial running

Technical Run Display



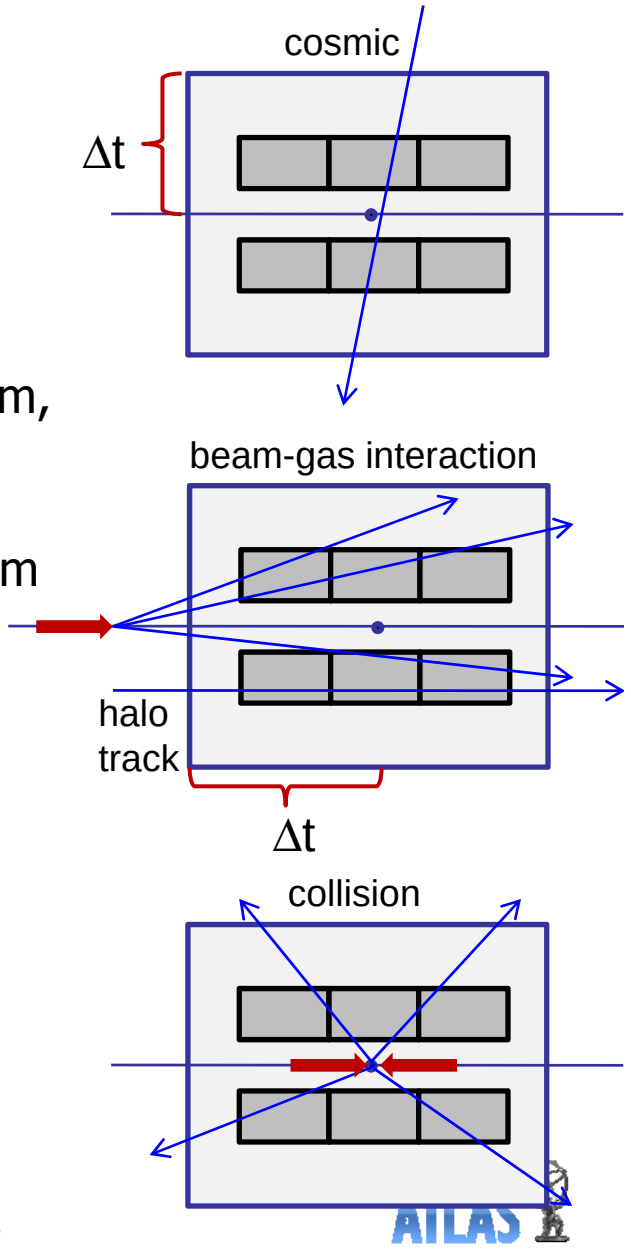
Looking ahead…

Looking ahead: Commissioning with beam

Activities during Beam Commissioning (expected end-July):

- Calibration triggers
  - Detector characterisation, timing
- Cosmic triggers
  - Exercise whole system, HLT, read out, TTC system,
  - Alignment data, coarse timing, synchronisation,
  - Monitoring, exercise reconstruction/ Tier 0
  - Verification of experiment protection without beam
- Single beam triggers
  - Validation of beam protection systems
  - Feedback to machine,
  - First synchronization with LHC
- Collision triggers
  - Full synchronization with LHC
  - Understanding of full detector
  - Physics ...

(Talk S6.4 today by Tetiana Hryn'ova)



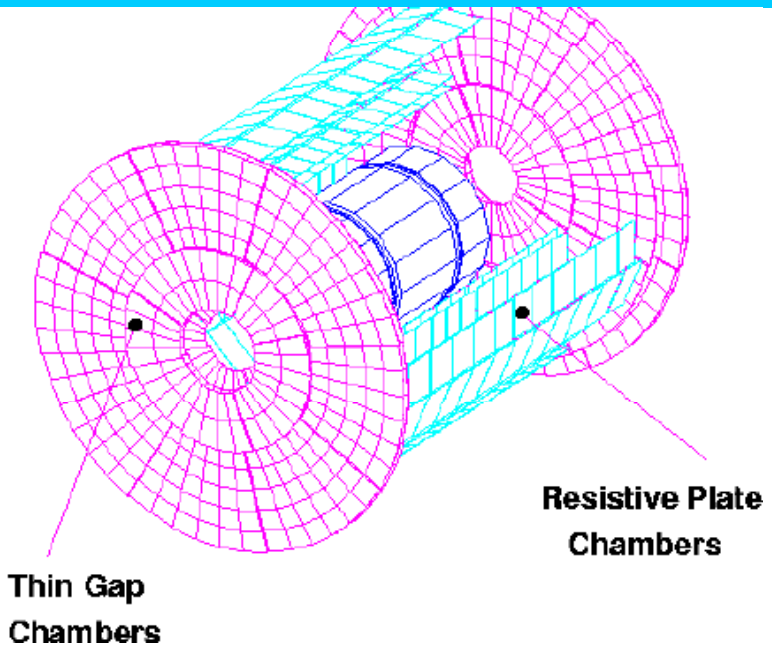
Conclusions

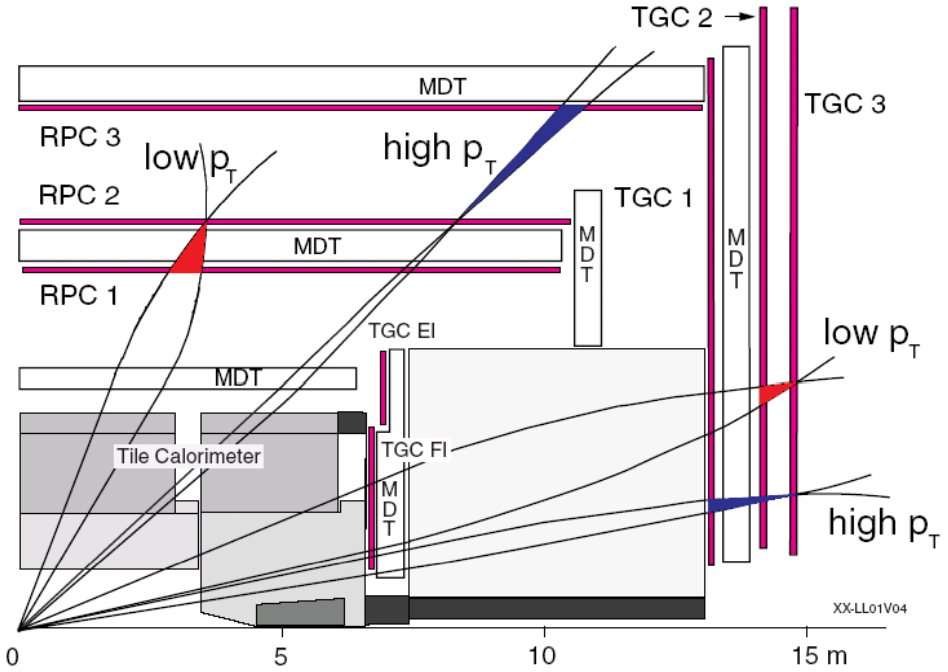
- ATLAS detector is fully installed in the cavern
- Last hardware work being done before beam-line closes, esp. in Muon (MDT) and Inner Detector (SCT and Pixel cooling) area
- Milestone weeks with cosmic, calibration and technical runs on-going:
  - Combined analysis
  - 'Real' triggers used
  - TDAQ integrating all subsystems
- Online and Offline software maturing, computing infrastructure being tested

- Moving into continuous runs and 24/7 shifts
- *Ready and waiting for collisions!*

BACKUP SLIDES

ATLAS Level-1 Muon Trigger





- Dedicated muon chambers with good timing resolution
  - Barrel: Resistive Plate Chambers (RPC)
  - Endcaps: Thin Gap Chambers (TGCs)
- Local track finding on-detector, candidate multiplicity calculation off-detector

- Looking for coincidences in chamber layers within programmable *roads* (road width related to momentum)
- 6 programmable coincidence windows determine momentum threshold (using B-field deflection)
- For cosmic rays open up the coincidence windows as much as possible

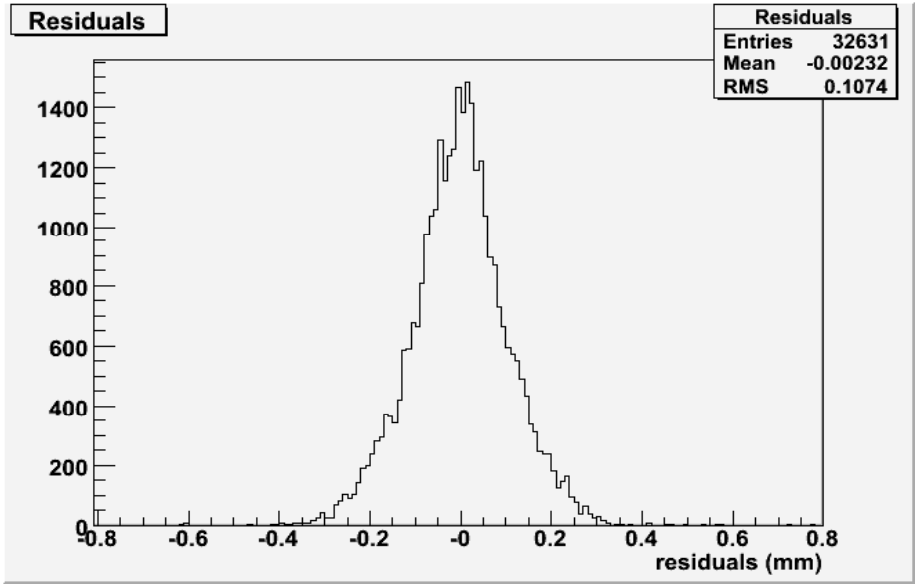
Inner Detector Installation Status

- Inner Detector consists of: Pixel, SCT, TRT
- Inner Detector preparation is behind schedule due to breakdown in cooling system compressors for SCT and Pixels:
  - Compressors dismantled and being repaired
  - During the repair SCT and Pixels cannot be operated
  - Repair will take until end of May at the earliest
  - Time available for Pixel commissioning sharply reduced
  - Beam-pipe closure possible only after cooling

Muon Barrel/EndCap Commissioning: Calibration

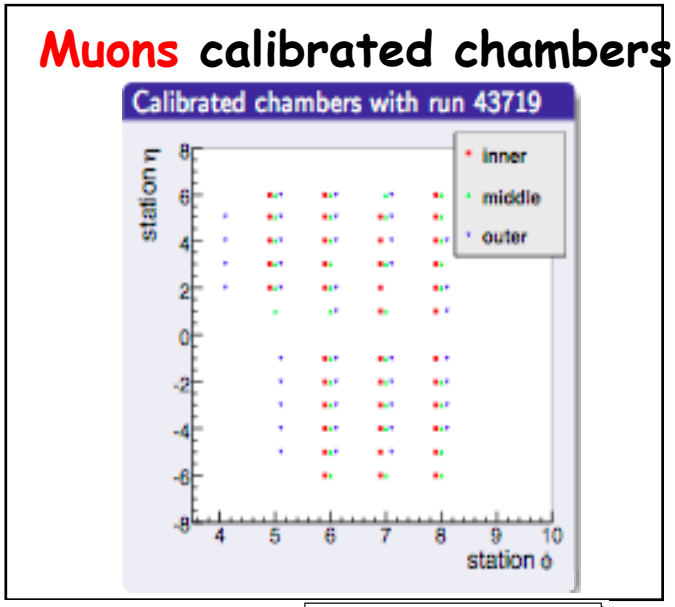
- The Muon Calibration Data Stream provides large samples of muon data extracted before the Level-2 decision (Only data in Region Of Interest marking by Muon Level-1 trigger).
  - During M4:
    - Calibration Stream emulated offline, data sent (offline) to Tier2-Computing centres
  - During Dec.'07 muon run:
    - Calibration stream extracted online from LVL2
  - Still many problems to investigate but very encouraging progress

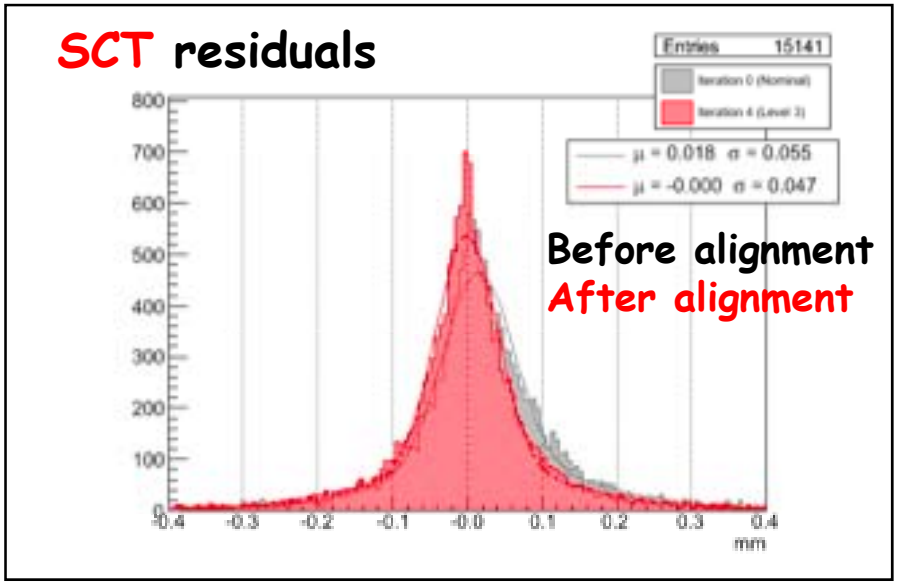
MDT Residuals from Cosmics after calibration on Calibration Stream Data

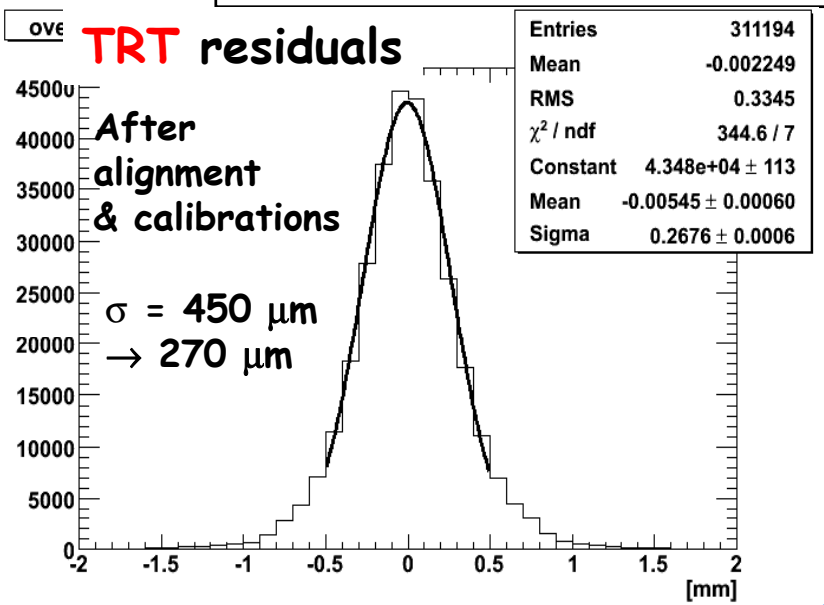


Cosmic data analysis: TRT+SCT

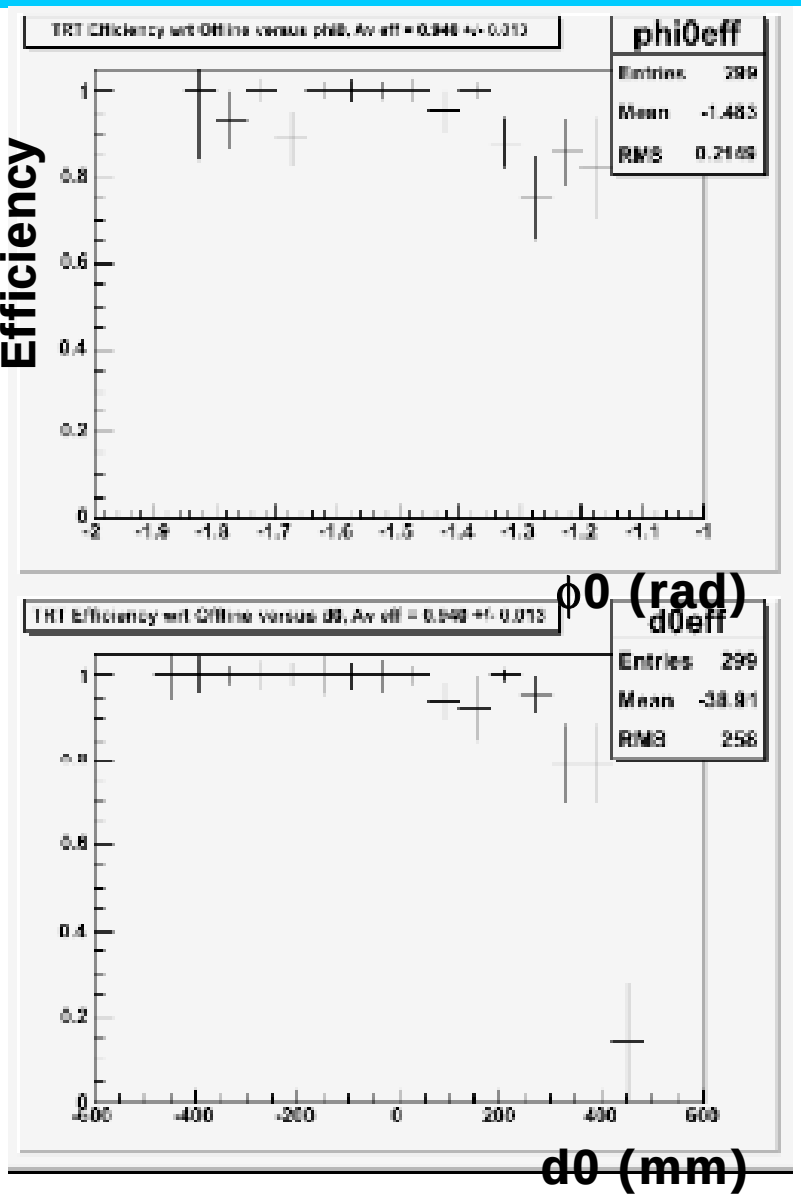
- Detailed studies performed for each sub-system have been performed, in particular:
  - ID alignment and calibration
  - Muons calibration
  - List of bad channels
  - Tile laser timing updated







Cosmic data analysis: HLT Tracks



High-Level-Trigger track (algorithm 'SiTrack' in LVL-2) Efficiency w.r.t. Offline tracks